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ABSTRACT

This report describes four individualized programs which simulate physical experiments in force and motion, graph and data collected by individual students, and provide feedback to each student relative to his generalizations. An overview of the unit is provided, descriptions of the unit and accessory materials are presented, sample runs of the four programs are included, and instructional objectives are listed. Instructions given the students concerning procedures for running the programs, instructions for the teachers in regard to use of the programs, and evaluation instruments are included. One section of the report describes a study which evaluated the classroom use of these computer-based simulation programs. Finally, the program and file listings for each of the four programs, and non-computer simulation problem sheets are provided. (DT)

Technical Report Series

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SCIENCE EDUCATION CENTER

The University of Iowa

July 1974

technical report 1

Newton's Law: A Computer-Based Simulation for Introductory Physics

by

Vincent N. Lunetta

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NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

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NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

UNIT OVERVIEW

technical report 1

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

PURPOSE

These four individualized programs simulate physical experiments in force and motion, graph the unique data collected by individual students, and provide feedback to each student relative to his generalizations. Film loops are available to improve the realism of each simulation.

ACCESS INSTRUCTIONS

```
Get-FORCEA
RUN
```

(Instructions for accessing successive programs are included within the first program of the series)

DESCRIPTION

These programs introduce Newton's Second Law through simulated laboratory experiences, and the Newton and Kilogram are defined. In using the programs, students improve their ability to make generalizations from graphed data and they will improve their understanding of motion and the property of inertia (Newton's First Law). The simulated experiments parallel a series of fundamental, inductive experiments developed by the Physical Science committee! The experiments are basic, yet to set up and adjust the real apparatus is a very time consuming process. This laboratory simulation is not designed to replace all first-hand experience with materials; however, the learning process can become more effective and efficient if appropriate laboratory work is supplemented with individualized, simulated experiments.

In each of the four programs the student must specify the variables for the particular experiment, e.g., the amount of force to be applied and the mass of the cart, in response to specific questions from the computer. The computer acts as "lab partner" and graphs the data: it then asks numerous questions about the regularities which are present. For example, the student has to determine acceleration from a graph of velocity vs. time in a couple of places.

If the student responds incorrectly, he is given assistance, and if he fails to grasp the concept after help has been provided more than once by the computer, he is instructed to see his teacher before preceding; the program is then automatically terminated. Each completed simulation ends by instructing the student to list the sources of experimental error as he envisions them and to state the conclusions which can be drawn from the experiment. He is encouraged to pursue the investigation further at home or in the lab.

SUGGESTIONS FOR TEACHERS

This simulated experiment series is most appropriately utilized after linear motion and the property of inertia have been discussed but prior to introducing Newton's Second Law. Since students will spend approximately 30 minutes on each of the four programs, scheduling is critical when large numbers of students are involved. If multiple terminals are not available, other materials such as vectors and circular motion may be discussed in class while students progress through the simulated experiments on their own time.

To insure that students complete the series of programs, teachers should ask them that they turn in completed programs or that they include them in their laboratory notebooks. When a student reports to his teacher because his program was terminated early and he needs additional help, he should bring the computer output with him for review with his teacher. The concept causing the difficulty will be apparent in the closing lines of the program output.

---

[1] Physical Science Study Committee, PHYSICS LABORATORY GUIDE, 2nd Edition Heath 1965, 35-37

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

DESCRIPTIONS OF THE UNIT AND MATERIALS

technical report 1

Description of the Force and Motion Unit

The series of simulations produced in this study parallel the fundamental, inductive experiments developed by the Physical Science Study Committee (PSSC) through which students generalize Newton's Second Law.[1] General objectives of the Force and Motion Unit for experimental and control groups are:

A. To provide the student with a detailed understanding of Newton's Second Law;

B. To help the student develop graphical skills and an ability to interpret graphed data;

C. To help the student develop inquiry skills.

A more detailed list of specific objectives for the unit stated in behavioral terms is included in a subsequent section of this report.

Film Loops. The simulated investigations begin as the student views a film loop showing a jet plane during take-off. The film loop places the student in the role of experimenter, and through over-printing he is asked questions which cause him to consider the variables affecting the acceleration of the plane. The film fades from the airplane to a laboratory environment wherein the student is shown how to measure the effects of variables upon the acceleration of a dynamics cart. After viewing a person working with the apparatus, students acquire simulated data that they must analyze. After their analysis of the data, they move through successive viewings of film loops and interactions with the simulated experiments.

---

[1] Physical Science Study Committee. Physics Laboratory Guide. Englewood, N.J.: D.C. Heath and Co., 1965, p. 35-37.

Programs. The simulations are broken into four major components, each developing one major idea as depicted in Figure 1. Program #1 (FORCEA) develops the concept that the velocity of an object changes at a constant rate when a constant force is applied, i.e., a constant force produces a constant acceleration. It also introduces the notion that the acceleration of a body is in some way inversely related to its mass. Program #2 (FORCEB) develops the idea that the acceleration of an object is directly related to the applied force. Program #3 (FORCEC) develops the idea that acceleration is inversely proportional to mass when the applied force is held constant. Program #4 (FORCED) synthesizes these concepts and develops Newton's Second Law from them; it also introduces the newton as the unit of force in the MKS system. Each program concludes with problems reviewing the concepts developed in the unit up to that point. Also, the student is asked to list the sources of experimental error as he envisions them and to state the conclusions which can be drawn from each investigation. He is encouraged to pursue each investigation further at home or in the laboratory.

Students interact with the computer through remote terminals using natural language messages to get unique data they are to analyze. Each computer program begins with a short question to assess whether or not the student has attained the competencies necessary to enter that phase of the unit. If he does not meet the entrance competency required in programs #2, #3, and #4, he is given a second chance to do so without any assistance. If he responds incorrectly the second time, he is told to review the previous program. If the computer determines that he does not meet the entrance competency at the beginning of program #1, he is given

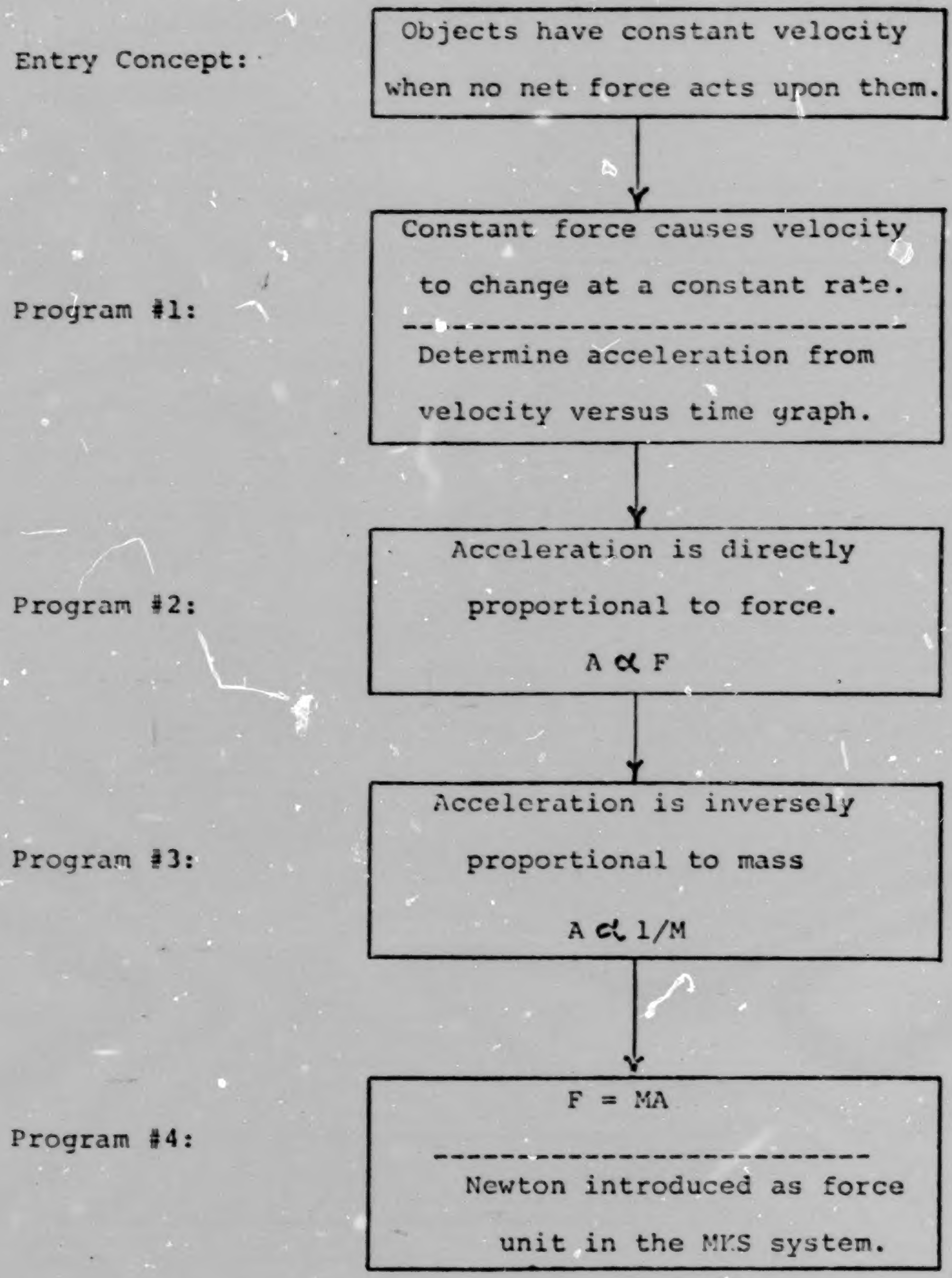
Entry Concept:
Objects have constant velocity when no net force acts upon them.
Program #1:
Constant force causes velocity to change at a constant rate.
Determine acceleration from velocity versus time graph.
Program #2:
Acceleration is directly proportional to force.
A ∝ F
Program #3:
Acceleration is inversely proportional to mass
A ∝ 1/M
Program #4:
F = MA
Newton introduced as force unit in the MKS system.

Figure 1. Sequence of Major Concepts in the Instructional Unit

assistance by means of typed messages. If he fails to respond correctly in three attempts, he is told to review certain materials before returning to the computer terminal.

After the student enters a particular program, the computer plays the role of the student's lab partner in a dialog mode. It asks questions which allow the student to specify the independent variables in the investigation such as the amount of force to be applied and the mass of the cart, and it generates unique data for the dependent variable "very similar to that obtained by experimenters using the real apparatus shown in the film loop." In data collection, the computer types out statements such as: "You make the simulated run with the cart applying a force of XXX (sprcified previously by the student), then I'll analyze the ticker tape, make a data table, and plot a graph of velocity versus time..."

The computer organizes and plots the data many times faster than the student can, thus allowing him to focus on the regularities apparent in the data instead of the algebraic manipulations necessary to graph the data. An even more important aspect of these dialogs are the questions the computer asks the student concerning generalizations which should be apparent in the data. At some points the student is asked to determine acceleration from a velocity versus time graph (slope). At another point he must note that a curve does not pass through the origin, and he is asked to explain why it does not do so.

Typed below is a short extract from program #2 which conveys the nature of the interactive dialog concerning graphed data:[2]

```
NOTE THAT THE GRAPH DOES NOT PASS THROUGH THE
ORIGIN.  APPARENTLY THE CART DOES NOT ACCELERATE
WHEN WE APPLY A SMALL POSITIVE FORCE.  WHAT
COULD CAUSE THIS?
?FRICTION
THERE IS FRICTION BETWEEN THE CART AND THE FLOOR
WHICH OPPOSES THE FORCE WE APPLY.  STUDY THE GRAPH
AND DETERMINE FROM IT THE FORCE OF FRICTION (IN LOOPS).
?.5
FINE! THE FORCE OF FRICTION IS REPRESENTED BY THE
INTERCEPT OF THE GRAPH WITH THE FORCE AXIS.
HAD WE USED A CART WITH GREATER FRICTION THAN IN
OUR EXPERIMENT WOULD THIS INTERCEPT BE TO THE
RIGHT OR LEFT OF ITS PRESENT LOCATION?
?RIGHT

CORRECT! NEXT, I'M GOING TO TAKE THE DATA WE
COLLECTED AND PLOT THE RESULTANT FORCE ACTING ON
THE CART, INSTEAD OF THE FORCE YOU APPLIED IN EACH
RUN.  (THE RESULTANT OR NET FORCE IS THE FORCE
YOU APPLIED MINUS THE FORCE OF FRICTION.)
TYPE IN THE POINT WHERE YOU THINK THE NEW PLOT WILL
INTERSECT THE FORCE AXIS.
?0
RIGHT! HERE'S THE NEW GRAPH:
```

For brevity only correct responses have been shown. Had a response been incorrect, a discussion of the particular item would have appeared, followed by further questions on the same point. If the student exceeds a certain error rate, he is told to consult with his teacher before continuing the program. A sample error branching sequence is shown diagrammatically in Figure 2. The dashed line in the Figure indicates that after providing help the teacher has the option of sending the student on to the next instructional sequence or returning him to the same instructional sequence in which he encountered difficulty. This particular program

---

[2] Question marks at the left edge of a line are followed by the student's response.

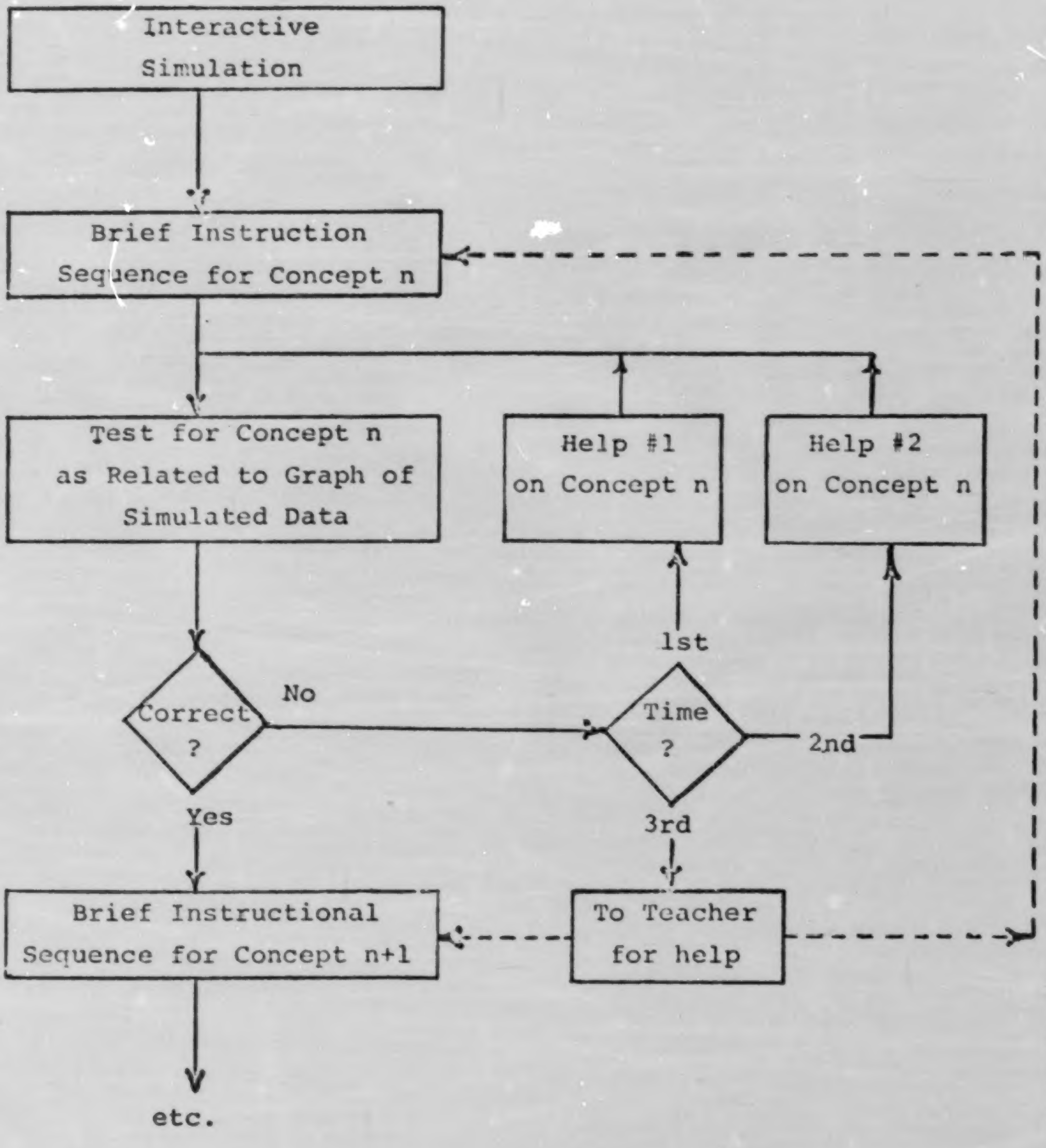
Interactive Simulation
Brief Instruction Sequence for Concept n
Test for Concept n as Related to Graph of Simulated Data
Help #1 on Concept n
Help #2 on Concept n
Correct ?
No
Yes
Time ?
1st
2nd
3rd
Brief Instructional Sequence for Concept n+1
To Teacher for help
etc.

Figure 2. Sample Branching Sequence

segment extracted from program #2 is followed by the plotting of a new graph, a brief discussion of that graph, and a dialog which asks the student to write an equation to fit the graph. The sample computer dialog runs included in this report should be reviewed individually for a more thorough overview of the interactive simulations.

Simulated Data and Problem Sheets. Data and problem sheets providing information very similar to that in the computer programs are included in the final section of this report. They are designed for use by students who do not have access to an appropriate computer facility. Each data and problem sheet reviews briefly the objectives of the particular investigation and then provides data "the experimenters gathered... from a careful analysis of the ticker tape pulled by the cart." Each student is asked to graph the data and discuss specific questions relating to the graphs on an "investigation work sheet."

Unit Development

The particular concepts taught in this instructional unit were selected for several reasons. They are fundamental in mechanics, they are readily amenable to graphical display as linear relationships, and the author has observed that few physics teachers have students do laboratory work in the area. Initial program writing was done in English language. During the lesson writing, main programs were completed before error loops were written. (Error loops provide help following the entry of an incorrect student response). The completed programs were then coded in BASIC. Certain other computer languages would have expedited program coding, but the BASIC language was the only language available to the author's students at that time, and it did not excessively constrain his initial objectives. In order to remain within a 5000 word core, each program in the series references a file in which messages are stored that do not contain variable quantities.

The lessons were altered in minor ways during encoding. Later they were revised based upon feedback from a small number of students who used the materials prior to widespread use of the programs.

The simulated data and problem sheets were prepared from the computer lessons after the computer lessons had been revised. Data appearing on these sheets were similar to that which is obtained by computer students, and the outline of the sheets parallels that of the computer programs. Questions and problems included in the computer programs are included on the simulated data and problem sheets. Correct answers are included for some of the problems, but most often the student is not provided with correct responses on the sheets. Feedback regarding the accuracy of his responses, if he is to get it, will come from other students, his teacher, or the graphed data.

Scripts for the film loops were written and initial filming was conducted concurrently with the initial program writing. Filming was done in Super 8mm on Kodachrome II film. After commercial processing, film clips were spliced into final form, and they were then commercially reproduced and placed in cartridges. (Titling was accomplished by filming through plates of glass on which block letters had been placed.)

Classroom Implementation

Teachers who use the Force and Motion simulations may bring their students through preliminary materials in a variety of conventional ways. (See Behavioral Objectives 1-4.) The students then progress individually at their own rates through the programs. Students normally schedule their programs outside of class time. Completed programs are to be submitted on certain dates which are specified in advance.

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

SAMPLE PROGRAM RUNS

technical report 1

```
GET-FORCEA
RUN
FORCEA


WELCOME TO OUR SIMULATED PHYSICS LAB. THROUGH THIS SERIES OF
PROGRAMS AND FILM LOOPS WE WILL INVESTIGATE HOW
FORCE AFFECTS THE MOTION OF AN OBJECT.
HAVE YOU WATCHED THE FILM LOOP FORCE & MOTION I?

USE ONLY NUMERALS AND CAPS FOR ANSWERS

?YES

ONE INSTRUCTION BEFORE WE BEGIN: WHEN YOU'RE ASKED TO TYPE
IN NUMERICAL DATA, DO NOT TYPE THE UNITS OF THE ANSWER.  FOR
EXAMPLE, AN ANSWER OF 10M/SEC SHOULD BE TYPED '10'.
EXPERIENCE TELLS US THAT WE MUST APPLY A FORCE TO CAUSE
AN OBJECT TO MOVE. IN THIS SERIES OF SIMULATED EXPERIMENTS WE
SHALL INVESTIGATE PHYSICAL VARIABLES WHICH AFFECT THE MOTION
OF AN OBJECT.  THE DATA WHICH WE WILL GENERATE WILL BE VERY
SIMILAR TO THAT OBTAINED BY EXPERIMENTERS USING THE REAL
APPARATUS SHOWN IN THE FILM LOOP.  I WILL BE YOUR LAB
PARTNER.

BEFORE WE CONTINUE, YOU SHOULD BE FAMILIAR WITH THE
PROPERTY OF INERTIA WHICH WAS DESCRIBED BY GALILEO AND
NEWTON.
IF A ROCK IS TRAVELLING THROUGH SPACE AT 100 M/SEC AND THERE ARE NO
FORCES ACTING ON IT, WHAT WILL BE ITS SPEED (IN M/SEC) 5 SEC. LATER?
?100

CORRECT!  DUE TO THE PROPERTY OF INERTIA (SOMETIMES CALLED
NEWTON'S 1ST LAW) AN OBJECT'S VELOCITY WILL BE CONSTANT
UNTIL AN UNBALANCED FORCE IS APPLIED. YET, IN WHAT WAY WILL
AN UNBALANCED FORCE CAUSE THE VELOCITY TO CHANGE?

IN THIS FIRST EXPERIMENT WE SHALL INVESTIGATE HOW AN
OBJECT'S VELOCITY CHANGES WHEN WE APPLY A CONSTANT FORCE.
WE SHALL APPLY A CONSTANT FORCE TO THE CART BY KEEPING ONE
LOOP OF RUBBER STRETCHED A CONSTANT LENGTH. (WE CAN
STRETCH OUR LOOP TO ANY LENGTH BETWEEN 50CM AND 100CM.)

TYPE BELOW THE AMOUNT OF STRETCH IN CM WHICH YOU INTEND TO APPLY DURING
THE RUNS THROUGHOUT THIS EXPERIMENT.
?50
YOU MAKE THE SIMULATED RUN WITH THE CART APPLYING A FORCE OF 50   CM.
THEN I'LL ANALYZE THE TICKER TAPE, MAKE A DATA TABLE, AND PLOT A GRAPH
OF VELOCITY VERSUS TIME.
HOW MANY BRICKS SHALL WE PLACE ON THE CART FOR A LOAD IN THIS RUN?
?1
I'VE PUT THE BRICKS ON --- AND THERE YOU GO PUSHING THE CART DOWN THE
HALL [illegible] A [illegible]!! ??
```

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```
HERE IS A DATA TABLE I'VE MADE FROM THE TICKER TAPE PULLED BY THE
CART IN THIS RUN:

TIME (SEC)  VELOCITY (CM/SEC)  [LOAD = 1      BRICKS  FORCE = 50    CM]
    .1             2
    .2             4
    .3             6
    .4             8
    .5             10
    .6             12
    .7             14.
    .8             16
    .9             18.
     1             20

HERE IS A GRAPH OF THE DATA:

        12    +                       X
              +
V       10    +                   X
E             +
L        8    +               X
O  (CM/SEC)   +
C        6    +           X
I             +
T        4    +       X
Y             +
         2    +   X
              +
         0    + + + + + + + + + + + + + + + + + + + + + +
              0  .1  .2  .3  .4  .5  .6  .7  .8  .9  1.0
                             TIME (SEC)
[LOAD = 1     BRICKS   FORCE = 50     CM]

STUDY THE DATA AND GRAPH. CAN YOU OBSERVE ANY REGULARITIES?
?YSS
PLEASE TYPE YES OR NO
STUDY THE DATA AND GRAPH. CAN YOU OBSERVE ANY REGULARITIES?
?YES

WHAT KIND OF RELATIONSHIP EXISTS BETWEEN VELOCITY AND TIME UNDER THESE
CONDITIONS (DIRECT OR INVERSE)?
?DIRECT

RIGHT!  IN FACT, THERE APPEARS TO BE A LINEAR RELATIONSHIP
BETWEEN VELOCITY AND TIME IF WE OVERLOOK THE SMALL IRREGU-
LARITIES PROBABLY CAUSED BY EXPERIMENTAL ERROR -- SUCH AS
VARIATIONS IN THE FORCE APPLIED.  THE CHANGE IN VELOCITY WAS
PROPORTIONAL TO THE TIME INTERVAL DURING WHICH THE FORCE
ACTED. WHEN WE APPLIED A CONSTANT FORCE TO THE CART THE
VELOCITY INCREASED AT A CONSTANT RATE.
FROM YOUR STUDY OF MOTION YOU WILL RECALL THAT ACCELERA-
TION IS THE RATE OF CHANGE OF VELOCITY.  THE ACCELERATION
OF AN OBJECT IS THEN THE SLOPE OF ITS VELOCITY V. TIME
GRAPH. (CHANGE IN V/CHANGE IN T).
[illegible] OUR
[illegible]
[illegible]
```

BEST COPY AVAILABLE

```
THE CONSTANT FORCE WE APPLIED IN THIS RUN DID PRODUCE A CONSTANT
ACCELERATION.
ANALYZE THE GRAPH AND DETERMINE THE ACCELERATION IN CM/SEC/SEC.
?20

OK.  OUR CONSTANT FORCE OF 50    CM CAUSED OUR CART TO HAVE A CONSTANT
ACCELERATION OF 20     CM/SEC/SEC.

BUT IS THE ACCELERATION ALWAYS CONSTANT UNDER THE INFLUENCE OF A
CONSTANT FORCE?
HOW WOULD THE DATA DIFFER IF WE HAD USED A DIFFERENT LOAD?
TO FIND OUT, LET'S CHANGE THE NUMBER OF BRICKS ON THE CART AND MAKE
ANOTHER RUN APPLYING THE SAME FORCE OF 50     CM.
HOW MANY BRICKS SHALL WE PLACE ON THE CART FOR A LOAD IN THIS RUN?
?2
I'VE GOT THE BUZZER ON: --- AND THERE YOU GO PUSHING THE CART DOWN THE
HALL FLEET-FOOTED AS A DEER!! ??

HERE IS A DATA TABLE I'VE MADE FROM THE TICKER TAPE PULLED BY THE
CART IN THIS RUN:

TIME (SEC)  VELOCITY (CM/SEC)  [LOAD = 2      BRICKS  FORCE = 50     CM]
    .1            1.33
    .2            2.66
    .3            3.99
    .4            5.32
    .5            6.65
    .6            7.98
    .7            9.31
    .8            10.64
    .9            11.97
    1             13.3

HERE IS A GRAPH OF THE DATA:

        12  +                                   X
            +                               X
V       10  +
E           +                           X
L        8  +                       X
O  (CM/SEC) +                   X
C        6  +
I           +               X
T        4  +           X
Y           +       X
         2  +
            +   X
         0  + + + + + + + + + + + + + + + + + + + + + +
            0   .1  .2  .3  .4  .5  .6  .7  .8  .9  1.0
                              TIME (SEC)
[LOAD = 2      BRICKS   FORCE = 50     CM]

STUDY THE DATA AND GRAPH. CAN YOU OBSERVE ANY REGULARITIES?
?[illegible]
```

BEST COPY AVAILABLE

```
THE CONSTANT FORCE WE APPLIED IN THIS RUN DID PRODUCE A CONSTANT
ACCELERATION.
ANALYZE THE GRAPH AND DETERMINE THE ACCELERATION IN CM/SEC/SEC.
?13.3

OK.  OUR CONSTANT FORCE OF 50   CM CAUSED OUR CART TO HAVE A CONSTANT
ACCELERATION OF 13.3         CM/SEC/SEC.


AS YOU CAN SEE OUR DATA ALSO INDICATE THAT THE MASS OF THE CART DID
AFFECT THE ACCELERATION.
WAS THE ACCELERATION GREATER OR SMALLER WHEN THE SMALLER MASS WAS
ACCELERATED?
?GREATER

CORRECT: THE SMALLER MASS UNDERWENT A LARGER ACCELERATION.
APPARENTLY THERE IS SOME KIND OF INVERSE RELATIONSHIP
BETWEEN THE MASS OF AN OBJECT AND ITS ACCELERATION WHEN A
CONSTANT FORCE IS APPLIED.  WE WILL FURTHER INVESTIGATE THIS
RELATIONSHIP IN THE THIRD EXPERIMENT IN THIS SERIES.
TO SUMMARIZE: WE CAN SEE FROM THE GRAPHS OF OUR DATA THAT
WHEN A CONSTANT FORCE WAS APPLIED TO A CART WITH A PARTI-
CULAR MASS THE ACCELERATION WAS CONSTANT.

NOW, LET'S TRY ONE LAST PROBLEM.
IF AN AIRPLANE'S ENGINES PRODUCE A NET FORCE WHICH IS CONSTANT AND WHICH
ACCELERATES THE PLANE FROM 0 TO 100 M/SEC IN 20 SEC, WHAT WILL BE THE
PLANE'S VELOCITY IN M/SEC AT THE END OF 40 SEC?
?200

RIGHT! AGAIN, A CONSTANT FORCE CAUSES A MASS TO HAVE A CONSTANT
ACCELERATION.
BUT HOW WOULD THE ACCELERATION HAVE DIFFERED HAD WE APPLIED A DIFFERENT
FORCE?--THIS QUESTION WILL FORM THE BASIS FOR THE NEXT
EXPERIMENT IN THIS SERIES.

SINCE YOU HAVE BEEN STUDYING FORCE AND MOTION USING A SIMU-
LATED EXPERIMENT, YOU HAVE NOT HAD TO COPE WITH THE MANY
SOURCES OF EXPERIMENTAL ERROR PRESENT IN THE ACTUAL
APPARATUS.  IF YOU WERE TO DO THE REAL EXPERIMENT YOU WOULD
HAVE TO REDUCE SUCH ERROR BEFORE THE GENERALIZATIONS WE'VE
SEEN COULD BE OBTAINED. PERHAPS YOU WILL BE ABLE TO PURSUE
THE INVESTIGATION FURTHER AT HOME OR IN YOUR LAB.
AFTER YOU'VE SIGNED OFF THE TERMINAL ROLL OUT SEVERAL
EXTRA INCHES OF PAPER. ON THIS PAPER LIST THE SOURCES OF
EXPERIMENTAL ERROR AS YOU ENVISION THEM AND STATE THE
MAJOR CONCLUSIONS YOU CAN DRAW FROM THE EXPERIMENT.
INCLUDE THIS PAPER IN YOUR PHYSICS NOTEBOOK.  AS SOON AS
YOU HAVE THE OPPORTUNITY VIEW THE NEXT FILM LOOP 'FORCE &
MOTION II' AND THEN RUN 'FO[illegible]'.

TO SIGN OFF THE TERMINAL, TYPE 'BYE' AND PRESS THE RETURN KEY

[illegible]
```

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```
RUN
FORCEB

WELCOME AGAIN TO OUR SIMULATED PHYSICS LAB. IN THIS SECOND
EXPERIMENT OF THE SERIES WE WILL INVESTIGATE HOW FORCES AFFECT
THE ACCELERATION OF AN OBJECT. HAVE YOU COMPLETED FORCEA &
WATCHED THE FILM LOOP 'FORCE & MOTION II'?
?YES
IN OUR LAST EXPERIMENT WE OBSERVED THAT A CONSTANT FORCE GAVE OUR CART
WHAT KIND OF ACCELERATION?
?CONSTANT

RIGHT! NOW TO STUDY HOW ACCELERATION VARIES WHEN THE APPLIED FORCE IS
CHANGED WE'LL HOLD ALL OTHER VARIABLES (SUCH AS MASS) CONSTANT.
HOW MANY BRICKS SHALL WE PLACE ON THE CART THROUGHOUT THIS EXPERIMENT?
?4

AS YOU OBSERVED IN THE FILM, WE CAN VARY THE FORCE WE APPLY
BY USING DIFFERENT NUMBERS OF RUBBER LOOPS STRETCHED A CON-
STANT LENGTH; I SUGGEST 60 CM FOR ALL LOOPS IN THIS EXPERIMENT
YOU SPECIFY THE FORCE YOU'LL APPLY IN EACH TRIAL AND
MAKE THE SIMULATED RUN.   THEN I'LL DETERMINE ACCELERATION
FROM THE TICKER TAPE AND PLOT A GRAPH OF ACCELERATION V.
FORCE WHEN WE HAVE ENOUGH DATA.

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?
?2.5

WE DON'T HAVE ANY PARTIAL LOOPS IN OUR LAB. TYPE IN A WHOLE NUMBER.
?2

THE ACCELERATION IN THIS RUN WAS: 9.6          CM/SEC/SEC.

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?
?4

THE ACCELERATION IN THIS RUN WAS: 28.8         CM/SEC/SEC.

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?
?6

THE ACCELERATION IN THIS RUN WAS: 48    CM/SEC/SEC.

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?
?8

THE ACCELERATION IN THIS RUN WAS: 67.2         CM/SEC/SEC.

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?
?10

THE ACCELERATION IN THIS RUN WAS: 86.4         CM/SEC/SEC.

IF YOU'D LIKE TO MAKE ANOTHER RUN, TYPE 'RUN'; IF YOU'D LIKE ME
TO GRAPH A VS. F, TYPE 'PLOT'.
?RUN
```

BEST COPY AVAILABLE

```
HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?
?1

THE ACCELERATION IN THIS RUN WAS: 0      CM/SEC/SEC.

IF YOU'D LIKE TO MAKE ANOTHER RUN, TYPE 'RUN'; IF YOU'D LIKE ME
TO GRAPH A VS. F, TYPE 'PLOT'.
?RUN

HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?
?9

THE ACCELERATION IN THIS RUN WAS: 76.8         CM/SEC/SEC.

IF YOU'D LIKE TO MAKE ANOTHER RUN, TYPE 'RUN'; IF YOU'D LIKE ME
TO GRAPH A VS. F, TYPE 'PLOT'.
?PLOT

        100  +
             +                                       X
A       80   +                                   X
C            +                               X
C       60   +
E(CM/SEC/SEC)+                       X
L.      40   +
             +               X
        20   +
             +       X
         0   + + + + + + + + + + + + + + + + + + + + + +
             0   1   2   3   4   5   6   7   8   9  10
                             FORCE (LOOPS)

CAN YOU OBSERVE ANY REGULARITIES IN THIS GRAPH?
?YES
WHAT KIND OF RELATIONSHIP EXISTS BETWEEN ACCELERATION AND FORCE
(DIRECT OR INVERSE)?
?DIRECT

RIGHT! IN FACT, THERE APPEARS TO BE A LINEAR RELATIONSHIP
BETWEEN FORCE AND ACCELERATION IF WE OVERLOOK THE  IRREGULARITIES
PROBABLY CAUSED BY EXPERIMENTAL ERROR.

NOTE THAT THE GRAPH DOES NOT PASS THROUGH THE ORIGIN.
APPARENTLY THE CART DOES NOT ACCELERATE WHEN WE APPLY A
SMALL POSITIVE FORCE. WHAT COULD CAUSE THIS?
?FRICTION

THERE IS FRICTION BETWEEN THE CART AND THE FLOOR WHICH OPPOSES THE
FORCE WE APPLY. STUDY THE GRAPH & DETERMINE THE FORCE OF
FRICTION(IN LOOPS).
?1
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BEST COPY AVAILABLE

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FINE! THE FORCE OF FRICTION IS REPRESENTED BY THE INTERCEPT
OF THE GRAPH  WITH THE FORCE AXIS.

HAD WE USED A CART WITH GREATER FRICTION THAN IN OUR EXPERIMENT
WOULD THIS INTERCEPT BE TO THE RIGHT OR LEFT OF ITS
PRESENT LOCATION?  (TYPE 'RIGHT' OR 'LEFT')
?RIGHT

CORRECT! NEXT, I'M GOING TO TAKE THE DATA WE COLLECTED AND PLOT
THE RESULTANT FORCE ACTING ON THE CART, INSTEAD OF THE
FORCE YOU APPLIED IN EACH RUN. (THE RESULTANT OR NET FORCE
IS THE FORCE YOU APPLIED MINUS THE FORCE OF FRICTION.)

TYPE IN THE POINT WHERE YOU THINK THE NEW PLOT WILL INTERSECT THE
FORCE AXIS.
?0
RIGHT! HERE'S THE NEW GRAPH:

        100  +                                       X
             +                                   X
A       80   +                               X
C            +
C       60   +                       X
E(CM/SEC/SEC)+
L.      40   +               X
             +
        20   +       X
             +   X
         0   + + + + + + + + + + + + + + + + + + + + + +
             0   1   2   3   4   5   6   7   8   9  10
                             FORCE (LOOPS)

AGAIN, WE SEE A LINEAR RELATIONSHIP BETWEEN FORCE AND ACCELE-
RATION. NOTE THAT THOUGH THE INTERCEPT WITH THE FORCE AXIS
HAS BEEN MOVED, THE SLOPE OF THE GRAPH HAS NOT CHANGED.
FRICTIONAL FORCE DOES NOT APPEAR TO AFFECT THE SLOPE OF THE
ACCEL. VS. FORCE GRAPH.

WRITE AN EQUATION TO FIT THIS GRAPH. USE 'A' TO REPRESENT ACCELERATION
AND 'F' TO REPRESENT FORCE. USE 'K' TO REPRESENT THE SLOPE (DON'T
BOTHER TO CALCULATE IT). BEGIN THE EQUATION:  A=  ...
?A=KF

RIGHT!--BUT WHAT FACTORS WILL CAUSE THE SLOPE TO CHANGE?  WE'VE
OBSERVED THAT FRICTION HAS NO EFFECT. WHAT OTHER VARIABLE
MIGHT CAUSE THE SLOPE TO CHANGE?
?MASS

AS WE OBSERVED IN THE LAST EXPERIMENT, MASS HAS AN INVERSE
RELATIONSHIP TO ACCELERATION WHEN A CONSTANT FORCE IS
APPLIED.  IN THE NEXT EXPERIMENT WE'LL CONDUCT A QUANTITATIVE
STUDY OF THIS RELATIONSHIP.
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TO SUMMARIZE, WE CAN SEE FROM OUT DATA THAT ACCELERATION IS
DIRECTLY PROPORTIONAL TO THE NET FORCE WHEN THE MASS REMAINS
CONSTANT.  THE EQUATION FOR THE RELATIONSHIP IS: A=KF.  I
SHOULD EMPHASIZE THAT F REPRESENTS THE NET OR RESULTANT
FORCE: IT IS THE VECTOR SUM OF ALL FORCES ACTING ON THE
OBJECT.  NOW, TRY THIS PROBLEM:

A SPACESHIP IS ACCELERATING IN SPACE AT 10M/SEC/SEC DUE TO THE FORCE
PROVIDED BY ONE ROCKET ENGINE. SUDDENLY 2 MORE IDENTICAL ROCKETS ARE
IGNITED PROVIDING THRUST IN THE SAME DIRECTION AS THE FIRST. WHAT
ACCELERATION IN M/SEC/SEC DOES THE SHIP NOW EXPERIENCE?
?30

GOOD! HERE'S ANOTHER PROBLEM FOR YOU TO TRY:
IN 10 SEC AN OBJECT ACCELERATES FROM REST TO A SPEED OF 300CM/SEC
WHEN ACTED UPON BY A NET FORCE(F). AT THE END OF THE 10SEC
INTERVAL F BECOMES ONE-THIRD ITS ORIGINAL STRENGTH.
WHAT IS THE SPEED OF THE OBJECT AT THE END OF THE FIRST 20 SEC IN
CM/SEC?
?400

CORRECT!


YOU HAVE NOW COMPLETED THIS SIMULATED EXPERIMENT.  PERHAPS
YOU WILL BE ABLE TO PURSUE THE INVESTIGATION FURTHER AT
HOME OR IN YOUR LAB.

AFTER YOU'VE SIGNED OFF THE TERMINAL, ROLL OUT SEVERAL
INCHES OF PAPER.  ON IT LIST THE SOURCES OF EXPERIMENTAL
ERROR AS YOU ENVISION THEM AND STATE THE MAJOR CONCLUSIONS
YOU CAN DRAW FROM THE EXPERIMENT.  INCLUDE THIS PAPER IN
YOUR PHYSICS NOTEBOOK.
AS SOON AS YOU HAVE THE OPPORTUNITY VIEW THE NEXT FILM
LOOP 'FORCE & MOTION III', THEN RUN 'FORCEC'.

TO SIGN OFF THE TERMINAL TYPE 'BYE' AND PRESS THE RETURN KEY

DONE
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```
RUN
FORCEC

HELLO AGAIN. IN THIS THIRD PROGRAM OF THE SERIES WE WILL STUDY HOW A
CONSTANT FORCE ACCELERATES DIFFERENT MASSES. HAVE YOU COMPLETED 'FORCEB'
AND THEN VIEWED FILM LOOP 'FORCE & MOTION III'?
?YES

IN THE FIRST EXPERIMENT OF THIS SERIES WE OBSERVED THAT CONSTANT
FORCES CAUSE A BODY TO UNDERGO A CONSTANT ACCELERATION.  IN THE
LAST EXPERIMENT WE HELD THE MASS CONSTANT AND OBSERVED WHAT KIND OF
 RELATIONSHIP BETWEEN ACCELERATION AND FORCE?
?LINEAR

RIGHT. NOW TO STUDY HOW ACCELERATION VARIES WHEN THE OBJECT'S
MASS IS CHANGED WE'LL TRY TO HOLD ALL OTHER VARIABLES CON-
STANT. WE'LL APPLY THE SAME FORCE TO THE CART IN ALL RUNS BY
KEEPING ONE LOOP OF RUBBER STRETCHED A CONSTANT LENGTH. (WE
CAN STRETCH OUR LOOP BETWEEN 50 AND 100CM.)

TYPE BELOW THE AMOUNT OF STRETCH IN CM YOU WILL APPLY DURING THE
RUNS THROUGHOUT THIS EXPERIMENT.
?75

WE CAN VARY THE CART'S MASS BY USING DIFFERENT NUMBERS OF
IDENTICAL BRICKS FOR A LOAD. THE MASS OF THE EMPTY CART
WE'LL USE HAS BEEN ADJUSTED TO EQUAL THE MASS OF ONE BRICK.

YOU SPECIFY THE NUMBER OF BRICKS YOU'LL USE FOR A LOAD IN
EACH TRIAL AND MAKE THE SIMULATED RUN.  THEN I'LL DETERMINE
ACCELERATION FROM THE TICKER TAPE AND PLOT A GRAPH OF
ACCELERATION V. MASS.  REMEMBER, THE MASS YOU'RE ACCELERATING
IS ONE BRICK LARGER THAN THE LOAD YOU SPECIFY SINCE THE CART
HAS A MASS OF 1 BRICK.

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?
?0

YOU WILL FIND THAT IF YOUR CART HAS NO BRICKS ON IT AND YOU APPLY A
FORCE OF 75    CM THE CART WILL TAKE OFF SO FAST YOU WON'T BE ABLE TO
APPLY A CONSTANT FORCE. I SUGGEST AT LEAST 1 BRICK FOR A LOAD.
SO, AGAIN --

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?
?1
FOR YOUR TOTAL MASS OF 2      BRICKS, THE ACCELERATION
WAS: 30     CM/SEC/SEC.      [1/A= .033        ]

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?
?2
FOR YOUR TOTAL MASS OF 3      BRICKS, THE ACCELERATION
WAS: 20     CM/SEC/SEC.      [1/A= .05         ]
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HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?
?3
FOR YOUR TOTAL MASS OF 4      BRICKS, THE ACCELERATION
WAS: 15     CM/SEC/SEC.      [1/A= .066        ]

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?
?4
FOR YOUR TOTAL MASS OF 5      BRICKS, THE ACCELERATION
WAS: 12     CM/SEC/SEC.      [1/A= .083        ]

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?
?9
FOR YOUR TOTAL MASS OF 10     BRICKS, THE ACCELERATION
WAS: 6      CM/SEC/SEC.      [1/A= .166        ]

IF YOU'D LIKE TO MAKE ANOTHER RUN TYPE 'RUN'; IF YOU'D LIKE ME TO
GRAPH A VERSUS M TYPE 'PLOT'.
?7

YOU DIDN'T TYPE 'PLOT' OR 'RUN'. AGAIN, WHICH SHOULD WE DO?
?RUN

HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?
?7
FOR YOUR TOTAL MASS OF 8      BRICKS, THE ACCELERATION
WAS: 7.5          CM/SEC/SEC.      [1/A= .133        ]

IF YOU'D LIKE TO MAKE ANOTHER RUN TYPE 'RUN'; IF YOU'D LIKE ME TO
GRAPH A VERSUS M TYPE 'PLOT'.
?PLOT

A       24   +
C            +
C       20   +           X
E            +
L       16   +               X
E(CM/SEC/SEC)+
R       12   +                   X
A            +
T        8   +                               X
I            +                                       X
O        4   +
N            +
         0   + + + + + + + + + + + + + + + + + + + + + + +
             0   1   2   3   4   5   6   7   8   9   10  11
                           TOTAL MASS (BRICKS)

STUDY THE GRAPH CAREFULLY. CAN YOU OBSERVE ANY REGULARITIES?
?YES

WHAT KIND OF RELATIONSHIP EXISTS BETWEEN ACCELERATION AND MASS (DIRECT
OR INVERSE)?
?INVERSE

RIGHT! AS THE CART'S MASS GETS LARGER THE ACCELERATION GETS
SMALLER UNDER THE INFLUENCE OF A CONSTANT FORCE.
```

```
OUR NEXT TASK IS TO FIND AN ALGEBRAIC EXPRESSION FOR THE
RELATIONSHIP BETWEEN ACCELERATION AND MASS.  A STUDY OF OUR
GRAPH SUGGESTS THAT IT MIGHT BE A 1ST POWER INVERSE RELATION-
SHIP. THAT IS: ACCEL. IS DIRECTLY PROPORTIONAL TO 1/MASS.
OR MASS IS DIRECTLY PROPORTIONAL TO 1/ACCELERATION.  TO CHECK
OUT THIS PREDICTION I WILL PLOT A NEW GRAPH OF 1/A VERSUS
MASS FOR EACH OF OUR TRIALS USING THE DATA WE COLLECTED.

HERE'S THE NEW GRAPH:

      . 24   +
             +
      . 20   +
             +
      . 16   +                                       X
             +                               X
 1/A  . 12   +
             +
      . 08   +                   X
             +           X
      . 04   +       X
             +
        0    + + + + + + + + + + + + + + + + + + + + + + +
             0   1   2   3   4   5   6   7   8   9   10  11
                        TOTAL MASS (BRICKS)

AHA!   VERY INTERESTING.
THIS GRAPH DOES MAKE THE RELATIONSHIP MORE OBVIOUS. DO YOU SEE WHAT
I MEAN?
?YES

THE LINEAR GRAPH INDICATES A DIRECT RELATIONSHIP BETWEEN THE TWO
VARIABLES WE'VE PLOTTED.

WRITE AN EQUATION TO FIT THIS GRAPH. DO NOT BOTHER TO CALCULATE THE
SLOPE: INSTEAD REPRESENT THE SLOPE WITH THE CONSTANT 'K'.
BEGIN THE EQUATION:  1/A=  ...
?1/A=KM

RIGHT! THERE IS A DIRECT RELATIONSHIP BETWEEN 1/A AND MASS:
K COULD OF COURSE BE REPLACED BY THE NUMERICAL VALUE FOR THE
SLOPE OF THE LINE.

HERE IS A PROBLEM FOR YOU TO TRY USING YOUR GRAPH AND THE
SIMULATED APPARATUS: A ROCK OF UNKNOWN MASS IS PLACED ON OUR
UNLOADED CART. YOU MAKE A RUN WITH IT APPLYING THE SAME FORCE
AS YOU DID IN THE OTHER RUNS. MY ANALYSIS OF THE TAPE INDI-
CATES AN ACCELERATION OF 15.0CM/SEC/SEC. WHAT IS THE TOTAL
MASS OF ROCK AND CART (TO THE NEAREST 10TH BRICK)?
?4

OK: THE MASS OF ROCK AND CART IS: 4      BRICKS.
WHAT IS THE MASS OF THE ROCK ALONE?
?3

GOOD! THIS IS ONE METHOD WHICH CAN BE USED TO DETERMINE THE
INERTIAL MASS OF AN OBJECT.
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TO SUMMARIZE, WE CAN SEE FROM THE GRAPHS OF OUR DATA THAT
THE ACCELLERATION OF AN OBJECT IS INVERSELY PROPORTIONAL TO
ITS INERTIAL MASS WHEN A CONSTANT FORCE IS APPLIED, AND
THE EQUATION YOU WROTE FOR THE RELATIONSHIP IS: 1/A=KM.

NOW TRY THIS PROBLEM:
A CAR HAS A MAXIMUM ACCELERATION OF 8 M/SEC/SEC. IF THE CAR TOWS
ANOTHER CAR OF IDENTICAL MASS AND DESIGN, WHAT WILL BE THE MAXIMUM
ACCEL. IN M/SEC/SEC?
?4

GOOD! NOW HERE'S ANOTHER PROBLEM:
MASS A ACCELERATES AT 80 FT/SEC/SEC AND MASS B ACCELERATES AT
20 FT/SEC/SEC WHEN IDENTICAL FORCES ARE APPLIED.
WHAT IS THE RATIO: MASS A/MASS B?
?4/1

NO. THE PROBLEM ASKS FOR THE RATIO OF MASS A/MASS B. THIS IS
EQUIVALENT TO ACCEL.B/ACCEL.A DUE TO THE INVERSE RELATIONSHIP.

TRY THE QUESTION AGAIN.
WHAT IS THE RATIO: MASS A/MASS B?
?1/4

CORRECT!


YOU HAVE NOW COMPLETED THIS SIMULATED EXPERIMENT. PERHAPS YOU WILL BE
ABLE TO PURSUE THE INVESTIGATION FURTHER AT HOME OR IN YOUR LAB.

AFTER YOU'VE SIGNED OFF THE TERMINAL ROLL OUT SEVERAL EXTRA INCHES OF
PAPER. ON IT LIST THE SOURCES OF EXPERIMENTAL ERROR AS YOU ENVISION
THEM AND STATE THE MAJOR CONCLUSIONS YOU CAN DRAW FROM THE EXPERIMENT.
INCLUDE THIS PAPER IN YOUR PHYSICS NOTEBOOK.

AS SOON AS YOU HAVE THE OPPORTUNITY VIEW THE NEXT FILM LOOP 'FORCE &
MOTION IV' AND RUN 'FORCED'.

TO SIGN OFF THE TERMINAL TYPE 'BYE' AND PRESS THE RETURN KEY.

DONE
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```
FORCED

HI! IN THIS FINAL PROGRAM OF THE SERIES WE WILL DISCUSS WHAT
WE'VE LEARNED ABOUT FORCE AND MOTION AND INTRODUCE A SYSTEM
OF UNITS IN COMMON USE. HAVE YOU COMPLETED 'FORCEC' AND THEN
STOP
HEL-L001.E.3



05-14-74 02:42 PM  PORT #17
S
STOP
GET-FORCED
RUN
FORCED

HI! IN THIS FINAL PROGRAM OF THE SERIES WE WILL DISCUSS WHAT
WE'VE LEARNED ABOUT FORCE AND MOTION AND INTRODUCE A SYSTEM
OF UNITS IN COMMON USE. HAVE YOU COMPLETED 'FORCEC' AND THEN
VIEWED FILM LOOP 'FORCE & MOTION IV'?
?YES

IN THE FIRST EXPERIMENT WE OBSERVED THAT A CONSTANT FORCE
CAUSES A BODY TO UNDERGO A CONSTANT ACCELERATION. IN THE
2ND EXPERIMENT WE OBSERVED THAT ACCELERATION WAS DIRECTLY
PROPORTIONAL TO THE NET FORCE. IN THE 3RD EXPERIMENT WE
OBSERVED WHAT KIND OF RELATIONSHIP BETWEEN ACCELERATION AND
MASS?
?INVERSE

CORRECT! WE MAY WRITE THIS LAST STATEMENT AS:

1) M IS DIRECTLY PROPORTIONAL TO 1/A OR
2) A IS DIRECTLY PROPORTIONAL TO 1/M

FROM THE RESULTS OF EXPERIMENT 2 WE CAN WRITE:
3) A IS DIRECTLY PROPORTIONAL TO F

STATEMENTS (2) & (3) CAN BE COMBINED AND WRITTEN AS:
A IS DIRECTLY PROPORTIONAL TO F/M

AN EQUIVALENT STATEMENT IS:
MA IS DIRECTLY PROPORTIONAL TO F
OR: F IS DIRECTLY PROPORTIONAL TO MA

IN EQUATION FORM:
F=MA
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I'VE JUST TYPED A LOT OF INFORMATION HERE. READ IT CAREFULLY AND TYPE
'GO' WHEN YOU WANT ME TO CONTINUE.
?GO

IN THE EQUATION K IS A CONSTANT OF PROPORTIONALITY AND ITS
NUMERICAL VALUE DEPENDS UPON THE UNITS USED TO MEASURE FORCE,
MASS, AND ACCELERATION. IT WOULD HAVE A SPECIFIC VALUE IF WE
CONTINUED TO MEASURE FORCE IN 'BANDS' AND MASS IN 'BRICKS'.
THE UNITS WE USED HAPPENED TO BE CONVENIENT FOR US, BUT
THEY ARE NOT IN COMMON USE IN THE WORLD. THE EQUATION, OFTEN
REFERRED TO AS NEWTON'S 2ND LAW, IS PERHAPS THE MOST FUNDA-
MENTAL EQUATION IN CLASSICAL MECHANICS, AND THE UNIT OF FORCE
COMMONLY USED IS DEFINED SO THAT K IN THE EQUATION = 1.

IN SCIENTIFIC WORK A VERY COMMON UNIT OF MASS IN USE TODAY
IS THE KILOGRAM (KG). THE BASIC UNIT OF FORCE WILL CAUSE A
MASS OF 1 KILOGRAM TO ACCELERATE AT 1M/SEC/SEC. THIS UNIT OF
FORCE IS CALLED THE NEWTON (N). IN OTHER WORDS A FORCE OF 1N
WILL CAUSE A MASS OF 1KG TO ACCELERATE 1M/SEC/SEC. USING THESE
UNITS THE EQUATION IS WRITTEN:

F=MA

1N=1KG M/SEC/SEC

TRY THE FOLLOWING PROBLEM USING THE MKS (METER,KILOGRAM,
SECOND) SYSTEM OF UNITS. A 600KG SPACESHIP IS PROPELLED BY
A ROCKET ENGINE. ITS ACCELERATION IS 2M/SEC/SEC.
WHAT IS THE NET FORCE (IN NEWTONS) ACTING ON THE SPACESHIP?
?1200

CORRECT! NOW HERE'S A SLIGHT VARIATION OF THE SAME PROBLEM:
AN 80KG ASTRONAUT IN EQUILIBRIUM OUTSIDE HIS SPACESHIP RECEIVES A
40N FORCE FROM A PROPULSION JET ATTACHED TO HIM.
WHAT ACCEL. (IN M/SEC/SEC) DOES HE EXPERIENCE?
?.5

RIGHT! IT IS IMPORTANT TO POINT OUT AS I DID IN EXP. 2 THAT F
REPRESENTS THE VECTOR SUM OF ALL FORCES ACTING ON THE OBJECT.

TRY THIS PROBLEM AGAIN WHICH INVOLVES NEGATIVE ACCELERATION: A 2000
KG CAR  IS TRAVELLING AT A SPEED OF 30M/SEC WHEN THE BRAKES
ARE APPLIED. THE CAR STOPS IN 15 SEC. IF WE ASSUME A CON-
STANT ACCELERATION, WHAT WAS THE FORCE (IN N) APPLIED BY THE
BRAKES?
?4000

GOOD! THE NEGATIVE BRAKING FORCE PRODUCED A NEGATIVE ACCEL.
IF THE VECTOR SUM OF THE FORCES ON A OBJECT = 0, THEN THE
OBJECT WILL UNDERGO 0 ACCELERATION. IN OTHER WORDS ITS
VELOCITY WILL NOT CHANGE.  HERE'S A PROBLEM ON THE SUBJECT:
TO PUSH MY STOVE ACROSS MY KITCHEN FLOOR AT A CONSTANT
SPEED OF 1M/SEC, I MUST APPLY A FORCE OF 250N.

WHAT IS THE FRICTIONAL FORCE ACTING ON THE STOVE IN N?
?250
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SURE! NOW TRY THIS PROBLEM: A FORCE OF 12N GIVES MASS A
AN ACCEL. OF 2M/SEC/SEC AND MASS B AN ACCEL. OF 6M/SEC/SEC.
WHAT IS THE ACCEL. (IN M/SEC/SEC) WHEN THE TWO ARE FASTENED
TOGETHER AND THE SAME FORCE IS APPLIED?
?1.5

GOOD!

THE LAST FEW QUESTIONS DEAL WITH THE GRAPH PRINTED BELOW
WHICH SHOWS THE VELOCITY OF A 10KG  OBJECT ALONG A STRAIGHT
PATH.
         10+
V          +
E         8+               X   X   X
L          +           X
O         6+       X                 X
C (M/SEC)  +   X
I         4X                           X
T          +                             X
Y         2+                               X
           +                                 X
          0+ + + + + + + + + + + + + + + + + + X + +
           0   2   4   6   8   10  12  14  16  18  20
                          TIME (SEC)

IN THE NEXT 3 QUESTIONS TYPE IN THE LETTER OF THE BEST
RESPONSE:

1. THE NET FORCE ACTING ON THE OBJECT WAS 0 AT: (A) 0 SEC; (B)
4SEC; (C) 10SEC; (D) 13SEC; (E) 16SEC; (F) NONE OF THE ABOVE
?C

CORRECT!

2. THE NET FORCE ACTING ON THE OBJECT WAS GREATEST AT:
(A) 0 SEC; (B) 4 SEC; (C) 10 SEC; (D) 13 SEC; (E) 16 SEC;
(F) NONE OF THE ABOVE.
?D

GOOD!

3. THE NET FORCE WAS CONSTANT BETWEEN:(A) 6-9SEC; (B) 9-13SEC;
(C) 13-15SEC; (D) 15-18SEC; (E) NONE OF THE ABOVE
?B

INCORRECT. THE FORCE IS CONSTANT WHERE THE ACCEL. IS CONSTANT.
REMEMBER THAT THE ACCEL. AT ANY POINT IS THE SLOPE OF THE V VERSUS T
GRAPH. FIND THE LISTED TIME INTERVAL IN WHICH VELOCITY CHANGES AT A
CONSTANT RATE. AND TYPE IN THE CORRECT ANSWER.
?D

CORRECT!
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```
4. WHAT WAS THE ACCEL. OF THE OBJECT (IN M/SEC/SEC) AT 6 SEC?
?.5
FINE!

5. DETERMINE THE NET FORCE (IN N) AT 6 SEC. (OBJECT HAS MASS OF 10KG)
?60

WRONG. F=MA. MULTIPLY THE MASS(10KG) BY THE ACCEL. CALCULATED IN THE
LAST PROBLEM. CHECK YOUR CALCULATIONS AND TYPE IN THE CORRECT ANSWER.
?5

VERY NICE.


YOU'LL NOTICE ON THE GRAPH THAT THIS CONSTANT FORCE OF 5N WAS APPLIED
FROM 0SEC THROUGH 8 SEC. NOW, THE FINAL PROBLEM:
6. DETERMINE THE FORCE (IN N) ACTING AT 13 SEC.
?20

OK! IT'S A GOOD IDEA TO WRITE THIS FORCE AS -20N SINCE
THE FORCE IS OPPOSITE THE DIRECTION IN WHICH THE OBJECT IS
MOVING.

THE IDEAS WE'VE BEEN DISCUSSING IN THESE FOUR PROGRAMS ARE
FUNDAMENTAL IN CLASSICAL MECHANICS. OUR UNDERSTANDING OF THEM
HAS BEEN GREATLY ENHANCED BY THE BRILLIANT INSIGHTS PROVIDED
BY GALILEO, NEWTON, AND THEIR SUCCESSORS.  THE STORY OF THE WORK
OF THESE EARLY SCIENTISTS IS FASCINATING READING.
THESE IDEAS PROVIDE A STARTING POINT FOR FURTHER STUDY IN
MECHANICS.  VERY SOON, FOR EXAMPLE, YOU WILL STUDY FALLING
BODIES. WHEN A BODY FALLS THE FORCE CAUSING IT TO ACCELERATE
IS ITS WEIGHT...

IT HAS BEEN VERY NICE WORKING WITH YOU IN THESE PAST FOUR
EXPERIMENTS. PERHAPS WE'LL MEET AGAIN IF SOMEONE WILL WRITE
MORE PROGRAMS...?

BEFORE WE PART, YOU'LL HAVE TO TYPE IN THE EQUATION REPRE-
SENTING NEWTON'S 2ND LAW WHICH WE DEVELOPED IN THIS PROGRAM.
BEGIN THE EQUATION: F= ... AND DO NOT INCLUDE A MULTIPLICATION SIGN.
?F=MA

AUF WIEDERSEHEN


TO SIGN OFF THE TERMINAL TYPE 'BYE' AND PRESS THE RETURN KEY.

DONE
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NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

INSTRUCTIONAL OBJECTIVES

technical report 1

GENERAL OBJECTIVES

General instructional objectives of the Force and Motion unit are:

A. to provide the student with a detailed understanding of Newton's Second Law;

B. to help the student develop graphical skills and an ability to interpret graphed data;

C. to help the student develop inquiry skills;

D. (for Group I students only) to familiarize the student with the computer.

BEHAVIORAL OBJECTIVES

The instructional objectives may be stated in more specific behavioral form. Prior to beginning the Force and Motion unit the student should have studied certain prerequisite concepts and skills for which the unit does provide reinforcement and a limited amount of assistance in the event of conceptual difficulty. When the student has mastered the entry concepts and skills he will be able to:

1. determine the acceleration of an object given data describing its change in velocity;

2. describe the velocity and acceleration of an object when no net force is applied (Newton's First Law);

3. determine the slope and intercept values when given a linear graph;

4. write an equation to fit the data when given a linear graph.

At the completion of the Force and Motion unit the student should have mastered additional concepts and process skills such that he should be able to:

5. determine the acceleration given the force applied to an object;

6. determine the force acting on an object given its acceleration (in Newtons or in arbitrary force units);

7. determine the mass of an object given the force applied and the resulting acceleration;

8. determine the applied forces given data describing the velocity of an object at various times;

9. describe the effects of forces on an inertial mass;

10. describe the effects of a constant force on the motion of an object;

11. determine the frictional force from a graph of force versus acceleration for an object;

12. describe the effects of friction on the acceleration of an object when a force is applied;

13. determine where velocity, acceleration, and force are maximum, constant, and minimum respectively given a velocity versus time graph;

14. fit an equation to a first order inverse relationship;

15. plot the velocity of an object as a function of time given a ticker tape pulled by the object through a timer;

16. describe the effects of experimental error on the variables under investigation.

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

MESSAGES TO STUDENTS AND TEACHERS

technical report

FORCE & MOTION

Computer Simulation

Message to Students

These four computer programs which you are about to use simulate experiments in force and motion. They will help you understand some basic ideas in physics. If you have never used a computer terminal before, don't panic, for it is much less intelligent than you are. It can, however, do some things faster than you can - as you will see. You don't have to know any special computer language to use these programs; it will help though, if you know how to use the English language!!

Typed below are some special instructions which will enable you to use the physics programs which are available in the computer.

1. Turn on Power (Power ON)
2. Dial - ___ ____ and listen for high pitch tone
3. Place phone in coupler
4. At Keyboard type: HEL - ____, ___ ; then press RETURN Key. (If all is well the computer will type: READY
5. Type: GET - $FORCEA, then press RETURN Key
6. Type: RUN

From here on all other instructions will be typed out for you by the computer. Read the messages carefully. Whenever a question mark appears on the left-hand side of the paper and the teletypewriter stops printing, you must type in a response and then press the RETURN key. The computer is looking for short responses in answer to its questions like: DIRECT, or 27, or CONSTANT.

Here are three notes of procedure:

1. To represent the number one (1) you must use the key labeled with the numeral 1 which is located at the left of the top line on the keyboard.

2. To represent the quantity zero, you must use the key labeled 0 located at the right of numeral 9 on top line of keyboard.

3. When making your responses, do not type in any extra spaces. (The computer has not been programmed to recognize them in these simulations.)

If you make an error in typing which you wish to correct before you press the RETURN key, one method you may use to correct your answer is: Hit the ESC (ESCAPE) key which is located in the upper left corner of the keyboard and then retype the correct answer.

To terminate: Type BYE then press RETURN key. Then Push Power ON switch and light will go off.

Make appropriate entry in LUNET LOG (time is expressed in minutes on data sheet such as: "006 minutes of terminal time."

The four Force and Motion programs are named: FORCEA; FORCEB; FORCEC; FORCED.

FORCE & MOTION

Computer Simulations

To: Physics Teachers

SUBJECT: Instructions regarding students whose programs have been terminated due to poor understanding of a concept.

A non threatening attitude should exist such that students whose programs have been terminated due to poor understanding of a concept readily come for consultation with their teachers. After discussing the concept thoroughly with the student, the teacher may recommend one of the following three options:

1. The student should rerun the entire program from the beginning in order to gain additional experience.

2. The student should proceed with the next program in the series if the teacher feels that the student understands the concept well and would not profit from rerunning the program.

3. The student should begin again, in the middle of the program which was terminated, and complete the remaining part of the program.

The following table indicates line numbers at which students can restart their programs. The instructions to be typed into the computer after signing on are, e.g.

```
GET-FORCEA
RUN-910
```

Program	Starting Point	RUN
FORCEA	Problem at the end of the program	910
FORCEB	Problems at the end of the program	1260
FORCEC	Problems at the end of the program	1270
FORCED	80 kg astronaut problem	460
	Braking car problem	580
	Kitchen stove problem	700
	2 masses fastened together	800
	Graph problems	880

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

EVALUATION INSTRUMENTS

technical report 1

Evaluation Instruments

The instruments used in data collection for this unit include a criterion-referenced pretest, a criterion-referenced posttest, and a student attitude survey. A description of the evaluation instrument follows:

Pretest. This examination is a forty item, multiple choice response, criterion-referenced test which measures cognitive skills. Test items were adapted from several sources. The largest number of items were adapted from a set of tests developed by Harvard Project Physics.[3] Other items were written by the author, and some were constructed from problems in the PSSC text.[4] In a study conducted by the author, the KR_{21} reliability estimate was .85. The test may be administered to assess the entry behaviors of the students participating in the unit.

Posttest. This final examination is an alternate form of the Pretest. Numerical values in the items and the names of objects described in the test have been changed from those in the Pretest; also the item sequence is changed. Items on the test measure the attainment of the behavioral objectives specified in the objectives section of this report. The KR_{20} reliability estimate is .78. The test measures the student's cognitive growth attained through the unit when his score is contrasted with that on the Pretest.

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[3] Harvard Project Physics. Tests, Unit I. New York: Holt, Rinehart, and Winston, Inc., 1968.

[4] Physical Science Study Committee, op. cit., p. 332-334.

Student Attitude Survey. This survey was designed to assess the student's attitudes toward the method of presentation of the unit. The majority of items in the survey were adapted from items on an instrument developed to measure student attitudes toward Computer Assisted Instruction by Bobby R. Brown.[5]

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[5] Bobby R. Brown. "Student Attitude Toward Computer-Assisted Instruction." Computer-Assisted Instruction Center, Florida State University, Tallahassee, Florida.

FORCE & MOTION

TEST

DIRECTIONS: This is a 30 minute test. Do not open this test booklet until you are asked to do so.

When you do write on the answer sheet, be sure to use only an ordinary #2 pencil. No ink or ball point pans may be used.

Turn your answer sheet so that the blue striped area is on your right. In the upper left corner, write in the name of the school and your instructor on the appropriate lines. On the line labelled CITY write in the date.

In the upper right corner you will see a group of columns labelled "Print your name in the boxes provided...". Print your last name, your first name, and your middle initial in the boxes provided. If there are extra boxes, leave them blank.

In the lower right section of the answer sheet, print your GRADE, BIRTH DATE, and SEX in the columns provided.

Go down the column under each of the boxes in which you have entered a letter and blacken the space that contains the letter.

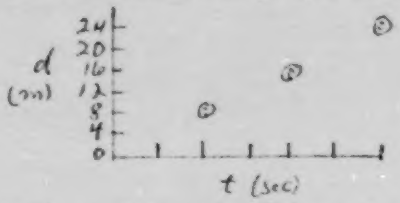
Make sure that all marks on the answer sheet are black and heavy and completely fill the answer spaces. Do not place any marks on the test booklet.

Answer all questions in the test by marking the letter on the answer sheet corresponding to the one best answer.

DO NOT OPEN THIS TEXT BOOKLET UNTIL YOU ARE ASKED TO DO SO.

1. An experiment yielded the data given in the table and graph below.

t (sec)	d (m)
0	0
2	8
4	16
6	24



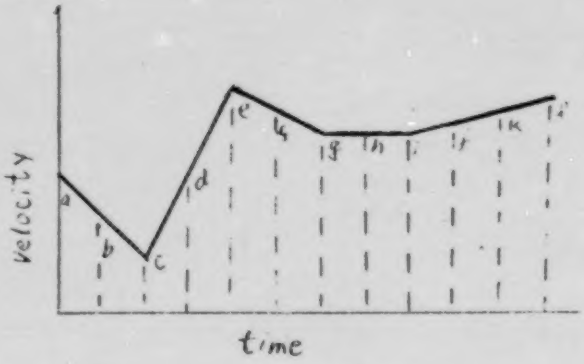
If these data are expressed as an equation, $d=kt$, the value of k is

A. 2 m/sec
B. 2 sec/m
C. 4 m/sec
D. 4 sec/m
E. 0.5 m/sec

2. Which of the following increases with time if a car moves with uniform velocity?

A. direction
B. displacement
C. acceleration
D. applied force
E. average velocity

Questions 3-7 refer to the graph at the right.



3. The speed is greatest at the time corresponding to point
A. a
B. c
C. d
D. e
E. k

4. The magnitude of the acceleration is greatest in the time interval

A. a to c
B. c to e
C. e to g
D. g to i
E. i to k

5. The applied force was 0 in the time interval

A. a to c
B. c to e
C. e to g
D. g to i
E. i to k

6. The magnitude of the applied force is greatest in the time interval

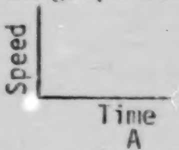
A. a to c
B. c to e
C. e to g
D. g to i
E. i to k

7. The applied force reaches its maximum negative value in the time interval

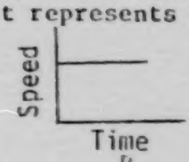
A. a to c
B. c to e
C. e to g
D. g to i
E. i to k

8. A car has a maximum acceleratkon of 4 m/sec^2. If it tows a second car having the same mass and design, the maximu acceleration will be
   A. 0 m/sec^2
   B. 2 m/sec^2
   C. 4 m/sec^2
   D. 6 m/sec^2
   E. 8 m/sec^2

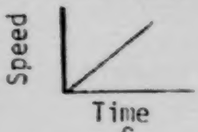
9. A cart, initially at rest, is pulled with a constant, unbalanced force. Which graph best represents how the speed of the cart changes with time?



A



B



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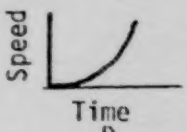

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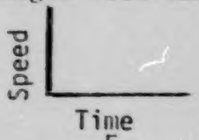
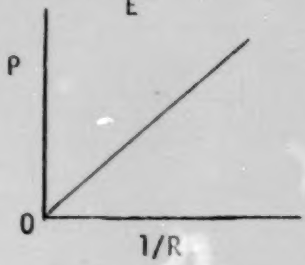


E

10. The equation of the line for the graph at the right is



A. $P = \frac{K}{R}$ D. $P = K\sqrt{R}$

B. $P = KR$ E. $P = KR^2$

C. $P = \frac{K}{R^2}$

11. A man pushes a puck on a frictionless horizontal surface with a force of 20 newtons. The resulting acceleration is 8.0 m/sec^2. What is the mass of the puck?

   A. 0.4 kg
   B. 2.5 kg
   C. 4.0 kg
   D. 10 kg
   E. 40 kg

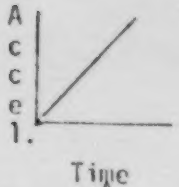
12. A car is slowed by a braking force that it comes to rest in 20 sec. If the car travels at the same speed and the braking force is doubled,

   A. the acceleration will be for times the previous value.
   B. the change in velocity will be doubled.
   C. the car will come to rest in 10 seconds.
   D. the car will come to rest in 40 seconds.
   E. the car will come to rest in half the distance.

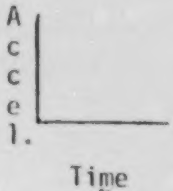
13. To push my desk across the floor at a constant speed of 2m/sec, I must apply a force of 200 newtons. The force of friction acting on the desk is

   A. 0 newtons D. 400 newtons
   B. 100 newtons E. Impossible to determine from the information given
   C. 200 newtons

14. Which of the following graphs shows the effects of a constant force?



A



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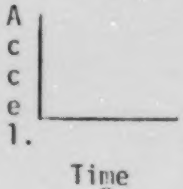

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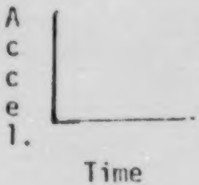
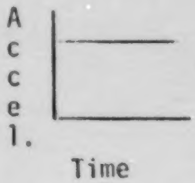


D



E

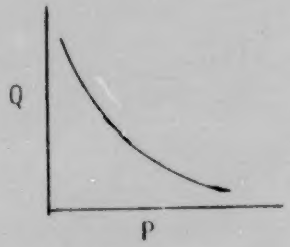
15. An astronaut in space gives a sudden push to a box that sends it away from him. Consider the following statements (assume friction is negligible).

1. The force exerted on the box by the astronaut is equal in magnitude to the force exterted on the astronaut by the box.
2. During the push the acceleration of the astronaut is equal in magnitude to the acceleration of the box.
3. The astronaut will accelerate for the same length of time as the box.

Which of the statements is true if the astronaut and the box have the same mass?

A. 1 only
B. 2 only
C. 3 only
D. 2 and 3 only
E. 1, 2, and 3

16. For the graph shown on the right, indicate the action you would take in order to work toward finding the relationship?

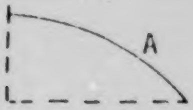


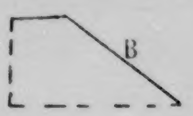
A. Square the P variable and graph Q vs. P^2
B. Take square root of P variable and graph Q vs. $\sqrt{P}$
C. No additonnal graph is needed.
D. Take inverse of P variable and graph Q vs. 1/P
E. Take square root of Q variable and graph $\sqrt{Q}$ vs. P

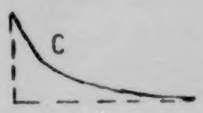
17. Measurements made on a ball rolling down a hill of unknown shape provided the following data:

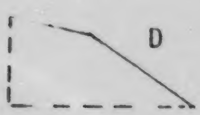
Time	Instantaneous Speed
0 sec	0 m/sec
1	6
2	12
3	18
4	20
5	22
6	24

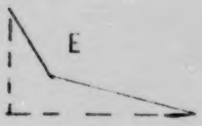
Which of the following diagrams represents the shape of the hill?



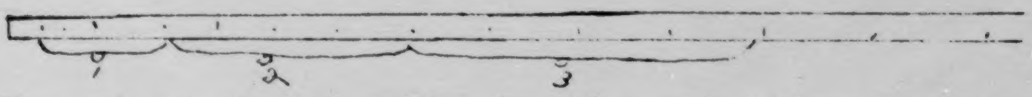




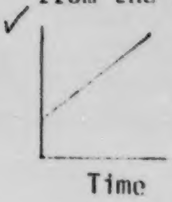


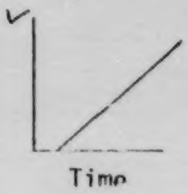


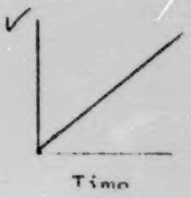
18.

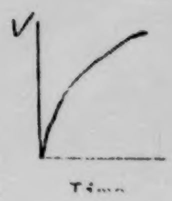


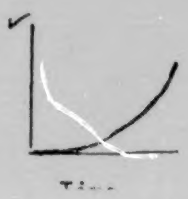
The graph most nearly describing the motion on the ticker tape above from the beginning of interval 2 is:











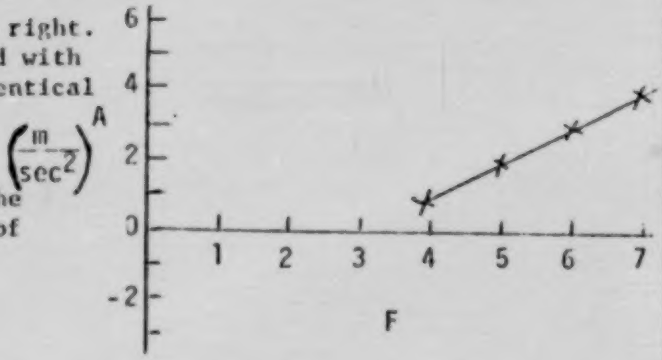
19. The acceleration of an object may be doubled by

A. doubling its mass
B. doubling its velocity
C. doubling its weight
D. doubling the net force acting upon it
E. none of the above

20. A railroad passenger car is at rest in a railway station. A boy sitting in the car flips a dime into the air; the dime hits the floor. Later, when the car is moving at a high constant speed, he flips the dime again in exactly the same way. Where does the dime hit the floor?

A. At the same spot on the floor as before
B. Ahead of where it hit before
C. Behind where it hit before
D. Impossible to determine from the information given

Questions 21 - 24 refer to the graph at the right. In each of several trials, a cart was pulled with a different number of equally-stretched, identical rubber bands. A constant acceleration was observed in each trial.



21. From the graph and your knowledge of the system, determine the number of bands of frictional force in the system.

A. 0
B. 1
C. 2
D. 3
E. Impossible to determine from the information given.

22. From your knowledge of the system and from the graph, predict the acceleration of the cart when a force of two bands is applied.

A. 2 m/sec/sec
B. -2 m/sec/sec
C. 1 m/sec/sec
D. -1 m/sec/sec
E. 0 m/sec/sec

23. If we change the surface on which the cart is pulled which of the following characteristics of the graph will probably change?

A. Slope and F-intercept
B. F-intercept only
C. Slope only
D. Neither the slope nor the F-intercept will chage
E. None of the above

24. An extrapolation of the graph produces an intercept on the force axis which is not 0. What does this indicate?

A. The mass of the cart was neglected
B. There was a deviation from Newton's Laws
C. There was another force acting in the direction of motion
D. There was another force acting opposite the direction of motion
E. None of the above

25. A 1000 kg car is travelling at 40 m/sec when the brakes are applied. If the car stops in 10 sec, the average force applied to stop the car is

A. 1000 newtons
B. 25 newtons
C. 250 newtons
D. 400,000 newtons
E. none of the above

26. All except one of the following require the application of a net force. Which one is the exception?

A. to maintain an object in uniform circular motion
B. to change an object from a state of rest to a state of motion
C. to change an object's speed without changing its direction of motion
D. to change an object's direction of motion without changing its speed
E. to maintain an object in motion at a constant velocity

27. A book is sitting at rest on a table. Which of the following statements best describes this situation?
A. There are no forces acting on the book.
B. The book is at rest in any coordinate system.
C. The book excerts no force on the table.
D. There are many forces acting on the book, but they balance each other.
E. None of the above.

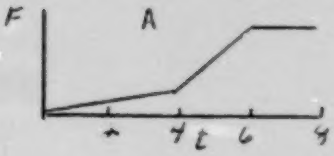
28. When the force applied to an object is constant, the object's acceleration and mass are
A. directly proportional
B. equal
C. unrelated
D. 0
E. inversely proportional

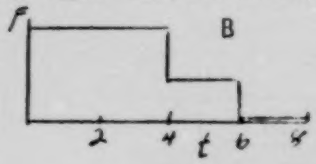
29. When the net force acting on a cart equals 0, the cart
A. must be at rest
B. may be in motion
C. may be speeding up
D. may be slowing down
E. none of the above

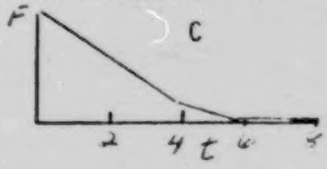
30. A plane having a mass of 10,000 kg. is launched from a catapult in 2.0 sec by a force of 400,000 newtons. Its average acceleration during launch was
A. 40 cm/sec^2
B. 1/40 m/sec^2
C. 400 m/sec^2
D. 1/400 m/sec^2
E. 40 m/sec^2

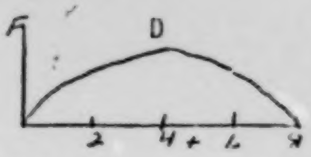
31. Given the velocity vs. time data at the right, select the force vs. time graph below that best illustrates that motion.

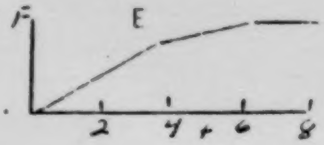
v	t
4	1
8	2
12	3
16	4
18	5
20	6
20	7
20	8





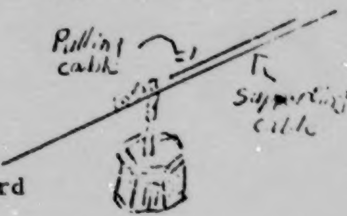






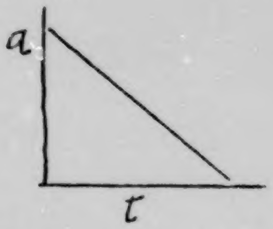
32. The diagram at the right shows a cable car supported by an overhead cable and pulled uphill by a second cable. Which of the following forces is 0 when the cable car moves with constant velocity?

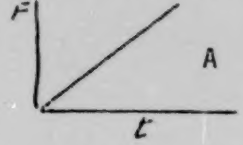
A. force of gravity on the car and carriage
B. force exerted by supporting cables
C. net unbalanced force on the car and carriage
D. frictional force on the wheels of the carriage
E. force exerted by the cable that pulls the car upward

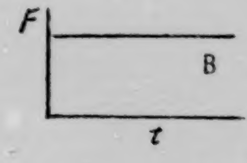


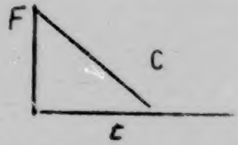
Given the graph at the left in each of the next three questions, pick the one at the right which most nearly describes the same phenomena. Examine the variables on the graphs carefully.

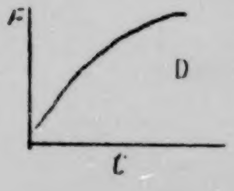
33.




A


B


C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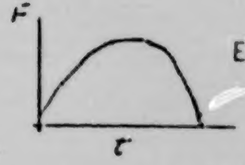
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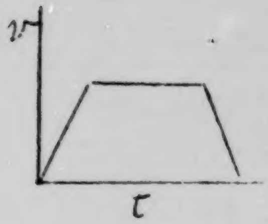
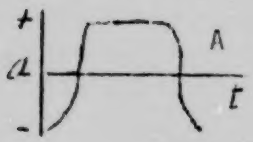
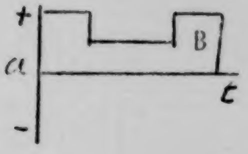
34.




A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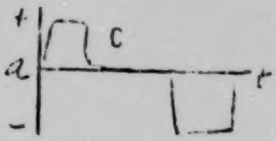
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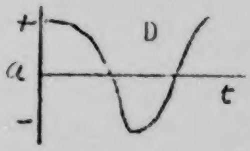
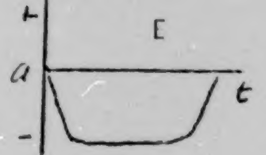
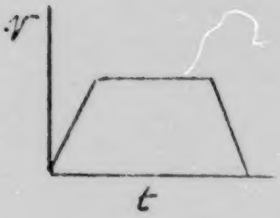
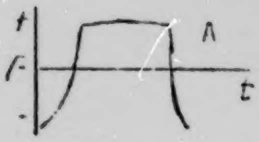
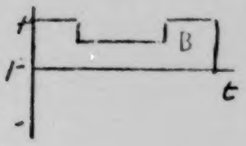

D


E

35.




A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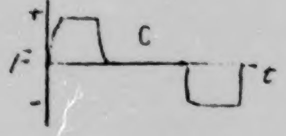
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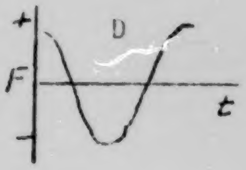
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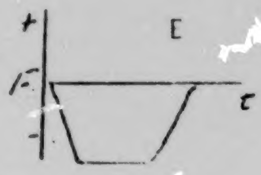
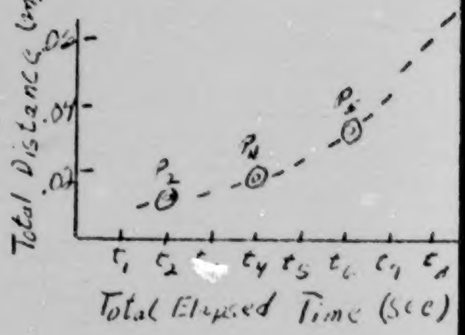

E

The graph at the right shows the relationship between the time and the total distance traversed by a glider moving on a nearly frictionless air track. Points P_2, P_4, and P_6 represent the experimental measurements. The dotted curve is a smooth curve drawn through these points. Questions 36 and 37 refer to this graph.



The slope of the curve at t_6 represents the

36. A. total distance traversed
    B. rate of change of speed
    C. instantaneous speed
    D. accelerat[illegible]
    E. average speed

37. If the values of the total distance traversed at times t_5, t_6, and t_8 are arranged in order of uncertainty with the most uncertain value of distance first, the order is:

    A. t_5 t_6 t_8

    B. t_8 t_5 t_6

    C. t_5 t_8 t_6

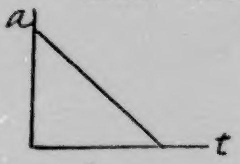
    D. t_6 t_5 t_8

    E. t_6 t_8 t_5

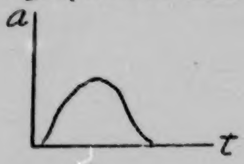
38. A player kicks a .5 kg ball so that it acquires a speed of 20 m/sec in .4 sec. What was the average force applied to the ball during the kick?

    A. 4 newtons
    B. 2.5 newtons
    C. 25 newtons
    D. 100 newtons
    E. 10 newtons

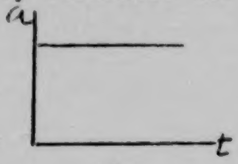
39. A low-friction cart is filled with sand and a constant force is applied. As the cart moves, the sand falls out through a hole in the bottom of the cart. Which graph most nearly describes the motion of the cart?



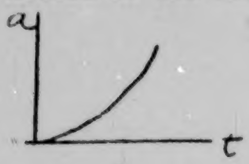
A



B



C



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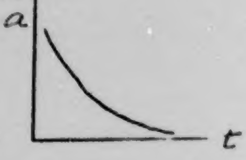


E

40. Car A has a mass of 400 kg; car B has a mass of 1200 kg. If both cars are given the same acceleration, what is the ratio of the force applied to car A over the force applied to car 8?

    A. 3
    B. 1
    C. .33
    D. .67
    E. 0

FORCE & MOTION

TEST

DIRECTIONS: This is a 30 minute test. Please do not open the test booklet until you are asked to do so.

When you do write on the answer sheet, be sure to use only an ordinary #2 pencil. No ink or ball point pens may be used.

Turn your answer sheet so that the blue striped area is on your right. In the upper right corner you will see a group of columns labelled "Print your name in the boxes provided ...". Print your last name, your first name, and your middle initial in the boxes provided. If there are extra boxes, leave them blank.

Go down the column under each of the boxes in which you have entered a letter and blacken the space that contains the letter. Do this for your last name, your first name, and your middle initial.

Make sure that all marks on the answer sheet are black and heavy and completely fill the answer spaces. Do not place any marks on the test booklet.

Answer all questions in the test by marking the letter on the answer sheet corresponding to the one best answer.

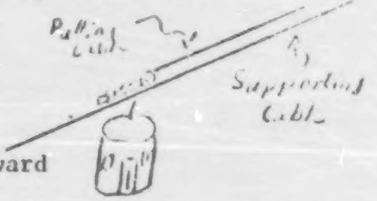
PLEASE DO NOT OPEN THIS TEST BOOKLET UNTIL YOU ARE ASKED TO DO SO.

1. When the net force acting on a car equals 0, the car
   A. must be at rest
   B. may be in motion
   C. may be speeding up
   D. may be slowing down
   E. none of the above

2. This test paper is sitting at rest on your desk. Which of the following statements best describes this situation?
   A. There are no forces acting on your paper.
   B. Your paper is at rest in any coordinate system.
   C. Your paper exerts no force on the desk.
   D. There are many forces acting on your paper, but they balance each other.
   E. None of the above.

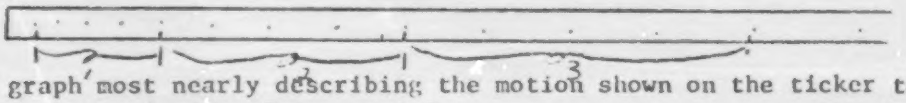
3. All except one of the following require the application of a net force. Which one is the exception?
   A. to change an object from a state of rest to a state of motion
   B. to maintain an object in motion at a constant velocity
   C. to change an object's speed without changing its direction of motion
   D. to maintain an object in uniform circular motion.
   E. to change an object's direction of motion without changing its speed

4. The diagram at the right shows a cable car supported by an overhead cable and pulled uphill by a second cable. Which of the following forces is 0 when the cable car moves with constant velocity?
   A. net unbalanced force on the car and carriage
   B. frictional force on the wheels of the carriage
   C. force of gravity on the car and carriage
   D. force exerted by supporting cables
   E. force exerted by the cable that pulls the car upward

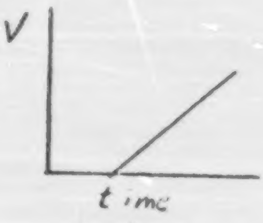


5. A subway car is at rest in a subway station. A boy sitting in the car flips a dime into the air; the dime hits the floor. Later, when the car is moving over a straight, level section of track at a high constant speed, he flips the dime again in exactly the same way. Where does the dime hit the floor?
   A. at the same spot on the floor as before
   B. ahead of where it hit before
   C. behind where it hit before
   D. impossible to determine from the information given
   E. none of the above

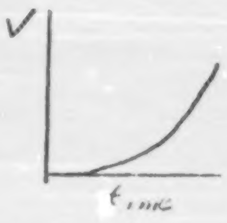
6.



The graph most nearly describing the motion shown on the ticker tape above from the beginning of interval 2 is:



A



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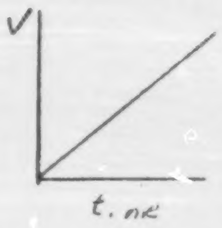

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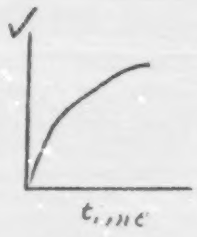
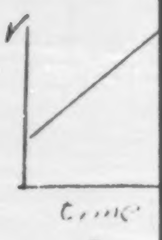


D



E

7. When the force applied to an object is constant, the object's acceleration and mass are
   A. directly proportional
   B. equal
   C. inversely proportional
   D. unrelated
   E. 0

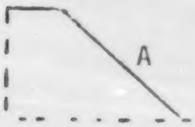
8. The acceleration of an object may be tripled by
   A. tripling its mass
   B. tripling its velocity
   C. tripling its weight
   D. tripling the net force acting upon it
   E. none of the above

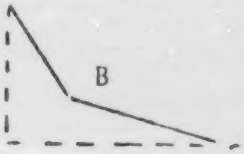
9. Which of the following increases with time if an object moves with uniform velocity?
   A. applied force
   B. average velocity
   C. acceleration
   D. direction
   E. displacement

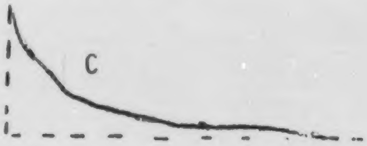
10. Measurements made on a ball rolling down a hill of unknown shape provided the following data:

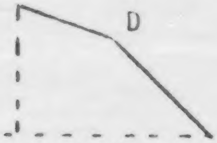
Time	Instantaneous Speed
0 sec	0 m/sec
1	6
2	12
3	18
4	20
5	22
6	24

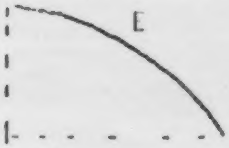
Which of the following diagrams represents the shape of the hill?



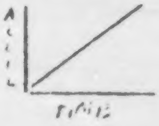




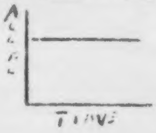




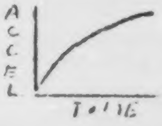
11. Which of the following graphs shows the effects of a constant force?



A



B



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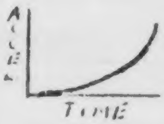
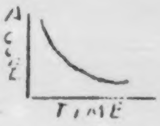
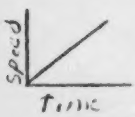


D

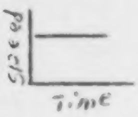


E

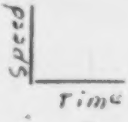
12. A car initially at rest, is pulled with a constant, unbalanced force. Which graph best represents how the speed of the cart changes with time?



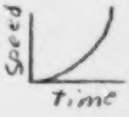
A



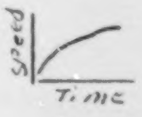
B



C



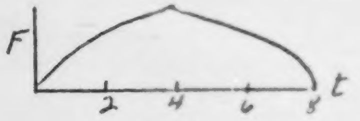
D



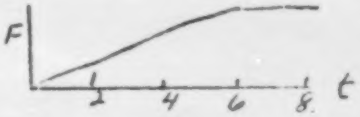
E

13. Given the velocity vs. time data at the right, select the force vs. time graph below that best illustrates that motion.

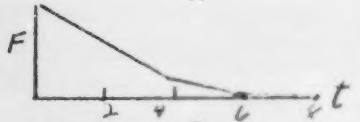
v	t
4	1
8	2
12	3
16	4
18	5
20	6
20	7
20	8



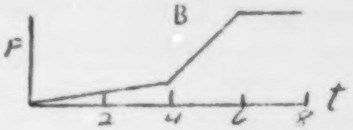
A



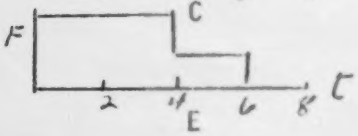
B



C



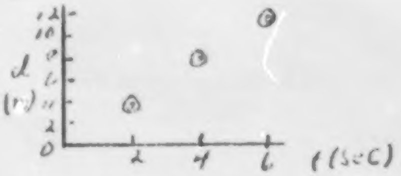
D



E

14. An experiment yielded the data given in the table and graph below.

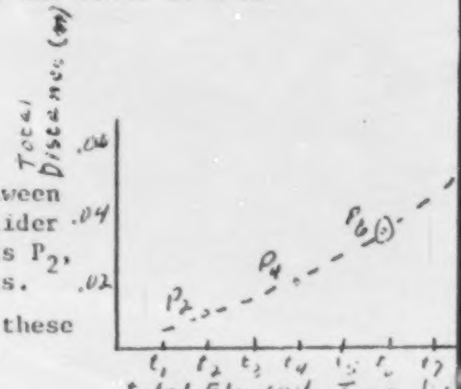
t (sec)	d (m)
0	0
2	4
4	8
6	12



If these data are expressed as an equation, d=kt, the value of k is

A. 1 m/sec
B. 1 sec/m
C. 2 m/sec
D. 2 sec/m
E. 0.5 m/sec

The graph at the right shows the relationship between the time and the total distance traversed by a glider moving on a nearly frictionless air track. Points P_2, P_4, and P_6 represent the experimental measurements. The dotted curve is a smooth curve drawn through these points. Questions 15 and 16 refer to this graph.



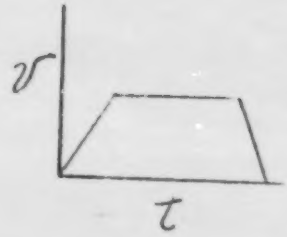
15. If the values of the total distance traversed at times t_5, t_6, and t_8 are arranged in order of uncertainty with the most uncertain value of distance first, the order is

A. t_5 t_6 t_8
B. t_6 t_8 t_5
C. t_5 t_8 t_6
D. t_6 t_5 t_8
E. • • •

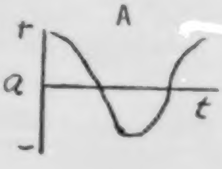
16. The slope of the curve at t_4 represents the
   - A. total distance traversed
   - B. instantaneous speed
   - C. acceleration
   - D. rate of change of speed
   - E. average speed

Given the graph at the left in each of the next three questions, pick the one at the right which most nearly descirbes the same phenomena. Examine the variables on the graphs carefully.

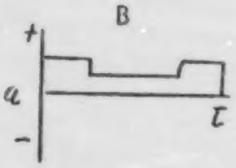
17.



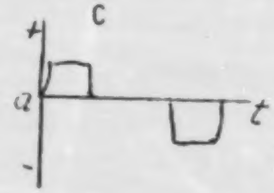
A



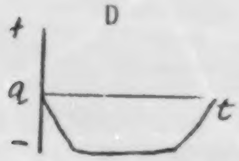
B



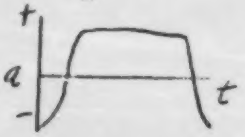
C



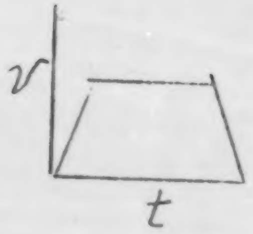
D



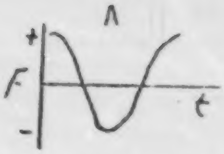
E



18.



A



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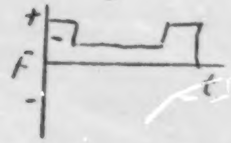

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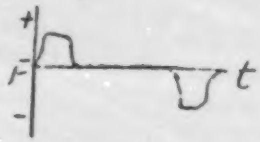
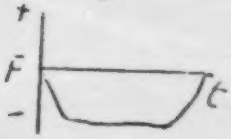


D



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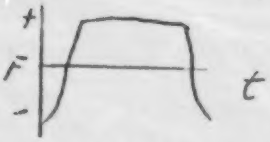
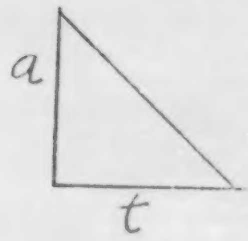
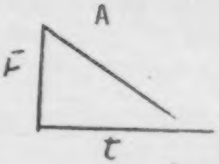


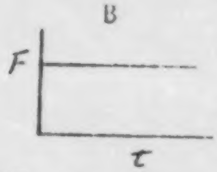
19.



A



B



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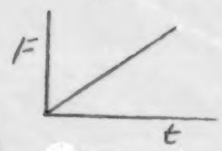
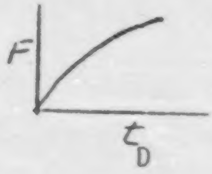
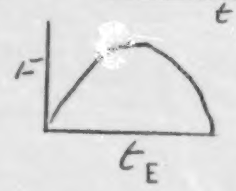
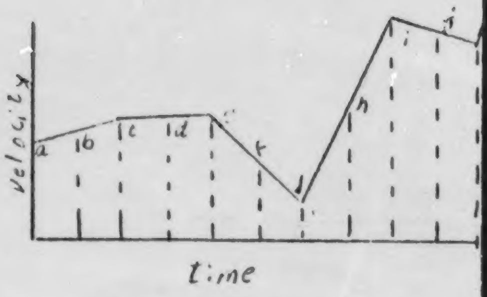








Questions 20 - 24 refer to the graph at the right.

20. The magnitude of the acceleration is greatest in the time interval
    A. a to c   D. g to i
    B. c to e   E. i to k
    C. e to g

21. The speed is greatest at the time correspondiing to point
    A. c   D. i
    B. g   E. k
    C. h

22. The magnitude of the supplied force is greatest in the time interval
    A. a to c   D. g to i
    B. c to e   E. i to k
    C. e to g

23. The applied force was 0 in the time interval
    A. a to c   D. g to i
    B. c to e   E. i to k
    C. e to g

24. The applied force reached its maximum negative value in the time interval
    A. a to c   D. g to i
    B. c to e   E. i to k
    C. e to g

25. To push my desk across the floor at a constant speed of 2 m/sec; I must apply a force of 150 newtons. The force of friction acting on the desk is
    A. 0 newtons   D. 300 newtons
    B. 75 newtons   D. Impossible to determine from the information given
    C. 150 newtons

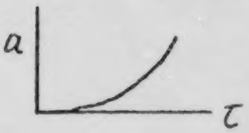
26. An ice skater gives a sudden push to a sled that sends it sliding away from him. Consider the following statements (assume friction is negligible).

    1. The force exerted on the sled by the skater is equal in magnitude to the force exerted on the skater by the sled.
    2. During the push the acceleration of the skater is equal in magnitude to the acceleration of the sled.
    3. The skater will accelerate for the same length of time as the sled.

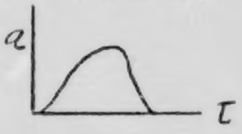
    Which of the statements is true if the skater and the sled have the same mass?
    A. 1 only
    B. 2 only
    C. 3 only
    D. 2 and 3 only
    E. 1, 2, and 3

27. A car is slowed by a braking force so that it comes to rest in 10 sec. If the car travels at the same speed and the braking force is doubled,
    - A. The acceleration will be four times the previous value.
    - B. The change in velocity will be doubled.
    - C. The car will come to rest in 5 seconds.
    - D. The car will come to rest in 20 seconds.
    - E. The car will come to rest in half the distance.

28. A low-friction cart is filled with sand and a constant force is applied. As the cart moves, the sand falls out through a hole in the bottom of the cart. Which graph most nearly describes the motion of the cart?



A



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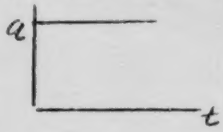
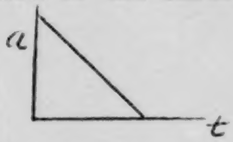
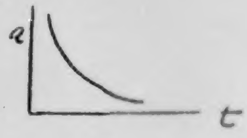


C

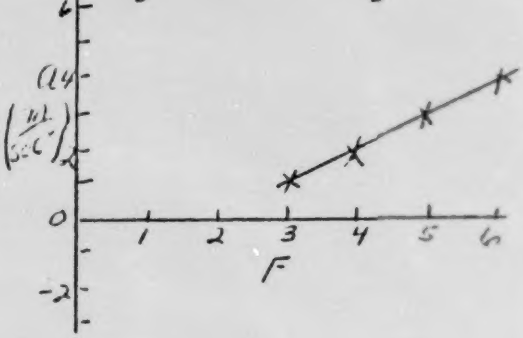


D



E

Questions 29 - 32 refer to the graph at the right. In each of several trials, a cart was pulled with a different number of equally-stretched, identical rubber bands. A constant acceleration was observed in each trial.



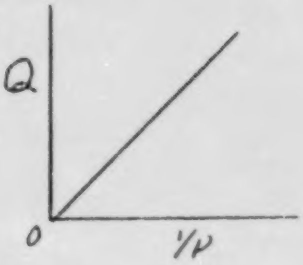
29. An extrapolation of the graph produces an intercept on the force axis which was not 0. What does this indicate?
    - A. The mass of the cart was neglected.
    - B. There was a deviation from Newton's laws.
    - C. There was another force acting in the direction of motion.
    - D. There was another force acting opposite the direction of motion.
    - E. None of the above.

30. From the graph and your knowledge of the system, predict the acceleration of the cart when a force of one band is applied.
    - A. 2 m/sec/sec
    - B. -2 m/sec/sec
    - C. 1 m/sec/sec
    - D. -1 m/sec/sec
    - E. 0 m/sec/sec

31. If we change the surface on which the cart is pulled which of the following characteristics of the graph will probably change?
    - A. slope and F-intercept
    - B. F-intercept only
    - C. slope
    - D. Neither the slope nor the F-intercept will change
    - E. none of the above

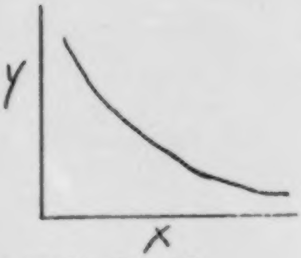
32. From the graph and your knowledge of the system, determine the number of bands of frictional force in the system.
    - A. 0
    - B. 1
    - C. 2
    - D. 3
    - E. impossible to determine from the information given

33. The equation of the line for the graph at the right is



A. $Q = \frac{K}{P}$
B. $Q = KP$
C. $Q = \frac{K}{P^2}$
D. $Q = K\sqrt{P}$
E. $Q = KP^2$

34. For the graph shown on the right, indicate the action you would take in order to work toward finding the relationship.



A. take inverse of x variable and graph Y vs. 1/X
B. take square root of x variable and graph Y vs. $\sqrt{X}$
C. no additional graph needed
D. square the x variable and graph Y vs. X^2
E. take square root of y variable and graph $\sqrt{Y}$ vs. X

35. A 2000 kg car is traveling at 50 m/sec when the brakes are applied. If the car stops in 10 sec. the average force applied to stop the car is
A. 8000 newtons
B. 300 newtons
C. 5 newtons
D. 800,000 newtons
E. none of the above

36. A man pushes a puck on a frictionless horizontal surface with a force of 10 newtons. The resulting acceleration is 4.0 m/sec^2. What is the mass of the puck?
A. 0.4 kg
B. 2.5 kg
C. 4.0 kg
D. 10 kg
E. 40 kg

37. Car A has a mass pf 500 kg; car B has a mass of 1500 kg. If both cars are given the same acceleration what is the ratio of the force applied to car A over the force applied to car B?
A. 3
B. 1
C. .33
D. .67
E. 0

38. A plane having a mass of 10,000 kg is launched from a catapult in 2.0 sec by a force of 300,000 newtons. Its average acceleration during launch was
A. 30 cm/sec^2
B. 1/30 m/sec^2
C. 300 m/sec^2
D. 1/300 m/sec^2
E. 30 m/sec^2

39. A car has a maximum acceleration of 5 m/sec^2. If it tows a second car having the same mass and design, the maximum acceleration will be
    A. 0 m/sec^2
    B. 2.5 m/sec^2
    C. 5 m/sec^2
    D. 7.5 m/sec^2
    E. 10 m/sec^2

40. A player kicks a .5 kg ball so that it acquires a speed of 10 m/sec in .2 sec. What was the average force applied to the ball during the kick?
    A. 4 newtons
    B. 2.5 newtons
    C. 25 newtons
    D. 100 newtons
    E. 10 newtons

FORCE & MOTION

Attitude Survey

DIRECTIONS: This is not a test of information; therefore, there is no one "right" answer to a question. We are interested in your opinion on each of the questions in this survey. Your opinions will be held strictly confidential. Do not hesitate to state exactly how you feel about each item. We are seeking information for an evaluation of the Force and Motion unit; please be "frank", and thank you for your help.

Please respond to each statement in the survey by marking your answer sheet according to the following code:

1. Strongly disagree
2. Disagree
3. Uncertain
4. Agree
5. Strongly agree

When you write on the answer sheet, be sure to use only an ordinary #2 pencil. No ink or ball point pens may be used.

Turn the answer sheet so that the blue striped area is on your right. In the upper left corner, write in the name of the school. On the line labelled CITY write in the date.

In the upper right corner you will see a group of columns labelled "Print your name in the boxes provided...". Print your last name, your first name, and your middle initial in the boxes provided. If there are extra boxes leave them blank. Go down the columns under each of the boxes in which you have entered a letter and blacken the space that contains the letter.

RESPONSES:
1. STRONGLY DISAGREE
2. DISAGREE
3. UNCERTAIN
4. AGREE
5. STRONGLY AGREE

1. I felt I could work at my own pace in the Force & Motion unit.
2. The unit made learning too mechanical.
3. I found it difficult to concentrate on the unit because of the method of presentation.
4. The method of presentation of the unit made me feel tense.
5. While working in the unit, I felt isolated.
6. Responses to my answers were helpful and appropriate.
7. The Force & Motion unit was an efficient use of a student's time.
8. I could have learned more if I hadn't felt pushed.
9. Even interesting material will be boring, if it is presented as the Force & Motion unit was.
10. I am not in favor of this kind of instruction because it depersonalizes education.
11. After studying the Force & Motion unit, I was interested in finding out more about the subject matter.
12. The method of instruction was too inflexible.
13. While working in the unit I felt as if someone were engaged in conversation with me.
14. The Force & Motion unit made it possible for me to learn quickly.
15. I was not concerned when I missed a question because no one was watching me.
16. While working in the unit I felt as if I had a private tutor.
17. The Force & Motion unit made allowances for students with different levels of understanding.
18. I enjoyed the method of instruction used in the unit.
19. The Force & Motion method of instruction denied me the opportunity for self expression.
20. I prefer lectures and demonstrations to the method of instruction used in the unit.

21. The Force & Motion unit helped me in understanding the role of computers.

22. The flexibility of scheduling the unit caused me to be too casual about getting on the computer system, and I let things go for too long before I tried to run the programs.

23. During the unit I was more involved in running the computer than in understanding the material.

24. While using the Force & Motion unit, I encountered serious mechanical malfunctions in the computer system.

RESPONSES: 1. STRONGLY DISAGREE
2. DISAGREE
3. UNCERTAIN
4. AGREE
5. STRONGLY AGREE

FORCE & MOTION

TEACHER REPORT

Name: School: Group:

Beginning date of unit (Pretest): Ending date of unit (1st Posttest):

# of class periods in unit: Length of class period:

Approximate homework time per class period/student:

Date of 2nd Posttest:

Texts used by physics classes in the study:

What portion of a typical week would you normally devote to student experimentation?

(Ex. 40 min/week) ________

To what extent did the experimental unit take the place of your usual coverage of the material?

How would you rate your teaching facility (equipment, supplies, room size)?

Ex.________ Good________ Fair________ Poor__________

How many years have you taught physics?

How many semester hours of course work have you had in the Physical Sciences?

0-10______ 10-20______ 20-30______ 30 or more______

Did the work with the experimental unit make excessive demands upon your time?

Yes______ No______ Comments:

What other area of science teaching do you think would benefit most from the development of a computer supplemented unit similar to Force & Motion?

Please use the reverse side to state other observations and evaluative comments.

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

EVALUATION OF CLASSROOM USE

technical report 1

Students learned the concepts using the two simulation modes described in this Report, and they participated in one of the following three instructional groups:

Group I (Experimental). These students interacted only with the film loops developed in the study and with computer interactive dialogs in which the computer played the role of the student's lab partner. The dialogs simulated physical experiments in force and motion, graphed the unique data collected by individual students, and provided feedback to each student relative to his generalizations.

Group II (Experimental). These students did not have access to computer terminals and interacted with the film loops and with simulated data and problem sheets and their teachers. The simulated data and problem sheets were prepared from the computer lessons after the computer lessons had undergone initial revision.

Group III (Control). These students studied the same concepts as did students in the experimental groups interacting with their teachers and with real laboratory materials as a normal part of their physics course. (The particular units were built largely around laboratory exercises III-1 and III-2 and supporting text materials of the Physical Science Study Committee.)

METHOD

Subjects

Subjects in the study were physics students in five public high schools in Massachusetts and Connecticut. These students were in classes which met the following criteria:

1. The Physics teacher was regarded as highly competent by colleagues in science education;
2. The teacher was interested in having his classes participate in the study and was able to coordinate necessary arrangements;
3. Group I classes were in schools having access to the computer system which was to be used in the study;
4. Group III classes used PSSC laboratory materials with teachers who had used the particular materials in previous years and who regarded the particular PSSC laboratory exercises as very important and effective learning modules;
5. The student groups had similar academic and socio-economic environments.

Procedure

Students participating in the study were selected from physics classes which were as similar as possible. All students within a particular class were members of the same group and were not aware of the activities of any of the other experimental or control groups.

Teachers in all groups brought their students through specified preliminary activities and then administered Pretests just prior to having their students begin the experimental unit. Immediately upon concluding unit activities, Posttests were administered to all students. The experimental unit was conducted in all classes within the first three months of the school year (September - December 1970), and activities during this period were carefully controlled and recorded. Following the first Posttest (Posttest #1) the classes participating in the study proceeded independently through various materials which were not experimentally controlled or recorded by the researcher.

In June of 1971, a second Posttest (Posttest #2) was administered to all students participating in the study. This second Posttest was identical to the one which had been taken by the students at the conclusion of the experimental unit. It was used to assess retention in the various experimental and control groups when scores were contrasted with those on the first Posttest. The Student Attitude Survey was also administered at this time to students in Groups I and II to assess their attitudes toward the experimental unit in the context of the entire physics course.

RESULTS

1. Which of the three instructional treatments produced best student performance?

Before the instructional groups were compared with each other, a t test was used to study the change in conceptual understanding from Pretest to Posttest #1 for each instructional group. Test data for each of the three instructional groups displayed in Table I indicated that student knowledge of physical concepts as measured by the tests was significantly higher at the conclusion of the unit than it was at the beginning.

To obtain a gross comparison of the effects of the instructional treatments, an analysis of variance (ANOVA) was conducted on the Pretest-Posttest #1 difference scores for the three groups. The analysis showed (Table II-A) that there were significant differences between the instructional groups; students in Group I had made the greatest gains followed by students in Groups II and III in that order.

TABLE I

PRETEST - POSTTEST #1 COMPARISON WITHIN EACH INSTRUCTIONAL GROUP

	Group I		Group II		Group III	
	Pre	Post #1	Pre	Post #1	Pre	Post #1
H	30	39	23	34	36	37
Q_3	19	28	17.5	26	22.5	26
Md	17	25	15	22	18	23
Q_1	13.5	22	13	18	15.5	20
L	9	12	5	10	10	14
$\overline{X}$	17.21	25.21	15.72	21.68	19.21	23.75
SD	4.49	5.37	3.85	5.01	5.27	5.05
N	57	57	57	57	57	57
t	13.27		11.95		9.45	

$t_{.01}$ (56df) = 2.67 $t_{.001}$ (56df) = 3.48

TABLE II-A

ANOVA OF PRETEST - POSTTEST #1 DIFFERENCE SCORES BY THE THREE INSTRUCTIONAL GROUPS

Source of Variation	df	Sum of Squares	Mean Square	F
Between groups	2	344.88	172.44	10.82
Within groups	168	2677.86	15.94	
Total	170	3022.74		

$F_{.01}$ (2df,168df) = 4.73 $F_{.001}$ (2df,168df) = 7.2

In order to further isolate the effects of instructional treatment upon concept learning, Tables II-B, C, and D display secondary analyses of variance comparing pairs of instructional treatment groups. Although secondary analyses must be interpreted with special care since a more rigorous basis than usual is required for rejection of the null hypothesis, these secondary analyses do show that differences between all pairs of groups were significant.

TABLE II-B

ANOVA OF PRETEST - POSTTEST #1 DIFFERENCE SCORES
BY GROUPS I AND III

Source of Variation	df	Sum of Squares	Mean Square	F
Between groups	1	340.43	340.43	20.09
Within groups	112	1898.14	16.95	
Total	113	2238.57		

$F_{.01}$ (1df,112df) = 6.87 $F_{.001}$ (1df,112df) = 11.4

TABLE II-C

ANOVA OF PRETEST - POSTTEST #1 DIFFERENCE SCORES
BY GROUPS I AND II

Source of Variation	df	Sum of Squares	Mean Square	F
Between groups	1	122.14	122.14	7.05
Within groups	112	1939.72	17.32	
Total	113	2061.86		

$F_{.01}$ (1df,112df) = 6.87 $F_{.001}$ (1df,112df) = 11.4

TABLE II-D

ANOVA OF PRETEST - POSTTEST #1 DIFFERENCE SCORES
BY GROUPS II AND III

Source of Variation	df	Sum of Squares	Mean Square	F
Between groups	1	54.75	54.75	4.04
Within groups	112	1517.86	13.55	
Total	113	1572.61		

$F_{.05}$ (1df,112df) = 3.93 $F_{.01}$ (1df,112df) = 6.87

2. Which of the three instructional treatments produced greatest efficiency of learning (gain in achievement per unit time)?

Table III displays a list of the mean time which students in the three instructional groups spent in unit activities, exclusive of time used for testing. Students in Group I spent a minimum of one hour and forty minutes at the computer terminals. No homework was done as part of the unit by students in this group. Group II classes spent six forty-minute periods on unit activities in class and approximately forty-five minutes were spent by each student in activities which were completed outside of class. Group III classes spent between nine and eleven fifty-minute periods in the unit and completed approximately twenty to thirty minutes of homework outside of class for each of these periods. In other words, Group III students spent approximately two full weeks in physics class on unit activities exclusive of test time.

TABLE III

TIME IN INSTRUCTIONAL ACTIVITIES

Group	Mean Time in Unit (minutes)	Group time ÷ Group I time	Group time ÷ Group III time
I	90	1.0	0.12
II	285	3.2	0.38
III	745	8.3	1.0

The two columns at the right side of Table III compare mean completion time for each instructional group with the mean completion time for Group I and Group III respectively. For example, on the average, Group III students worked in unit activities 8.3 times as long as students in Group I. Had concept learning been equivalent in all groups, then Groups I and II would have been 8.3 and 3.2 times more efficient respectively than Group III (control). However, concept learning was not equivalent. Information has already been presented indicating that Group I students achieved significantly higher gains during the instructional unit than did students in Group III. This means that the efficiency of learning in Group I was substantially greater than 8.3 to 1 when compared with learning in Group III. (Group II students fell between those in Groups I and III in both achievement and in time spent in instructional activities.)

3. What were the effects of the three instructional treatments upon retention?

The mean scores on Posttests #1 and #2 and the respective standard deviations for each instructional group are displayed in Table IV. It should be noted that Table IV includes only the scores of those students presented in Table I who also took Posttest #2. (Since Posttest #2 was administered late in the school year, some students in the study were not available to take that test.)

TABLE IV

POSTTEST #1 - POSTTEST #2 COMPARISON
WITHIN EACH INSTRUCTIONAL GROUP

Group	Test	Number of Students	Standard Deviation	Mean Test Score	t
I	Post #1	51	5.27	25.29	1.58
	Post #2	51	5.46	24.49	
II	Post #1	41	4.98	22.42	4.49
	Post #2	41	4.62	20.20	
III	Post #1	54	5.06	23.57	0.65
	Post #2	54	5.75	23.89	

$t_{.05}$ (40-60df) = 2.0

After analyzing the data using a Related t test for paired variables, Table IV shows that the null hypothesis was not rejected for Group I and Group III, i.e., a significant loss in knowledge during the six month period after the unit was not measured by the tests administered to these groups. Table IV shows that there was a significant drop in score from Posttest #1 to Posttest #2 for the students in Group II.

Table V displays a review of Pretest and Posttest #2 scores. The table shows that the null hypothesis was rejected for each of the three instructional groups. Thus, the gains in concept learning made by all instructional groups were still significant six months after completion of the unit.

TABLE V

PRETEST - POSTTEST #2 COMPARISON
WITHIN EACH INSTRUCTIONAL GROUP

Group	Test	Number of Students	Standard Deviation	Mean Test Score	t
I	Pre	51	4.24	17.41	12.55
	Post #2	51	5.46	24.49	
II	Pre	41	3.55	16.02	9.48
	Post #2	41	4.62	20.20	
III	Pre	54	5.08	18.87	9.48
	Post #2	54	5.75	23.89	

$t_{.001}$ (40-60df) = 3.5

4. How did the input variables of initial student intelligence, aptitude, grade level, and sex affect achievement?

To assess the effects of learner characteristics upon concept learning under the three instructional treatments, two way analyses of variance were run with Pretest - Posttest #1 difference scores for individual students as the dependent variable. Table VI summarizes the results of the analyses for six independent variables representing learner characteristics.

TABLE VI

TWO-WAY ANOVA OF PRETEST - POSTTEST #1 DIFFERENCE SCORES BY VARIABLE AND INSTRUCTIONAL GROUP -- SUMMARY

	Groups Compared		
VARIABLE	I - III	I - II	II - III
IQ	0	0	0
VPSAT	0	0	0
VPSAT interaction with instructional method	0	c	c
MPSAT	0	0	0
Pretest	b	0	b
Grade	0	0	0
Sex	c	c	0

b = H_0 rejected at .01 level.

c = H_0 rejected at .05 level.

0 = H_0 not rejected.

The table shows that IQ, VPSAT, MPSAT, and Grade did not significantly affect the concept learning which occurred during the instructional unit as measured by the evaluation instruments used in the study. Between Groups I and II and Groups II and III some interaction was observed between verbal aptitude and instructional method. Group II students having high verbal scores had substantially greater difference scores from Pretest to Posttest #1 than did students with lower verbal aptitude, and this phenomenon was not apparent in Group I or in Group III. From this data we might infer that reading ability was a greater factor contributing to achievement in Group II than in the other two instructional groups. It should be noted, however, that the Group II high verbal cell size was considerably smaller than the corresponding cells in the other two groups.

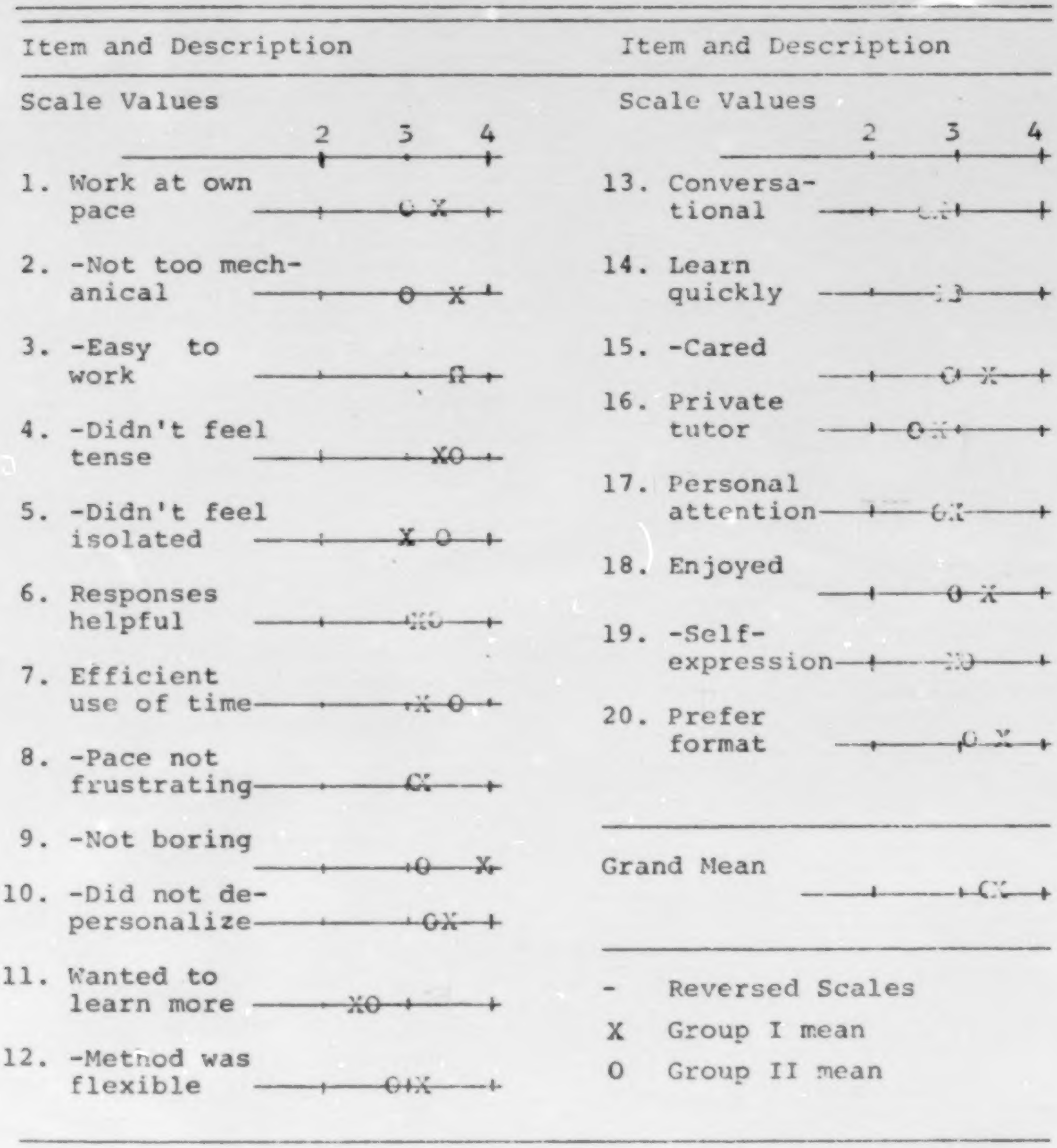
Table VI indicates that Pretest score did significantly affect concept learning when Group I was compared with Group III and when Group II was compared with Group III. With the exception of an inversion in Group III, mean Pretest-Posttest #1 difference scores were greater when mean Pretest scores were lower in all instructional groups. Concept learning means from Pretest to Posttest #1 were lower for the girls than for the boys in all instructional groups. Table VI indicates that secondary analyses of variance showed that Sex did significantly affect concept learning when Group I was compared with Group III and when Group I was compared with Group II.

5. What effect did the unit have upon student attitude in the two instructional treatment groups using simulated materials?

A mean attitude score was developed for each student from responses on the Attitude Survey which was administered to students in Groups I and II six months after the conclusion of the instructional unit, and correlations between these scores and other variables were investigated. The grand mean scores on the survey for both groups indicated generally favorable attitudes toward the mode of instruction; the Group I mean was slightly higher than the Group II mean. A review of individual item means for each group is presented in Table VII. A score of five represents maximum favorable attitude, a score of one represents maximum negative attitude, and a score of three represents a neutral attitude toward the instructional unit. Responses should be

TABLE VII

INSTRUCTIONAL GROUP ATTITUDE PROFILES



carefully scrutinized individually, but a review indicates, among other things, that students liked the instructional units (Group I higher than Group II) and that they felt the units were easy to use. Also, it is interesting to note that students in Group II perceived the unit as making more efficient use of their time than did students in Group I. Yet, cognitive data in the study showed the reverse to be true.

CONCLUSIONS

Analysis of data in this study showed that student learning of fundamental concepts in force and motion was significant in the two experimental groups and in the control group. It also showed that learning was significantly greater for students studying the concepts through computer simulation dialogs than for students in the second experimental group and in the control group. Furthermore, control students spent 8.3 times as long in instructional unit activities.

Students in the control group spent 3.2 times as long in instructional activities as did students in a second simulation group which did not have access to the computer dialogs. The achievement of this second group was significantly greater than that of the control group. This simulation group, however, had conceptual losses not experienced by the control group as measured on a second posttest administered six months after the completion of the instructional unit. (Students using the computer simulation dialogs showed no significant losses in conceptual understanding as measured on the second posttest.)

Student attitudes toward both simulated units were favorable.

The data indicated that in spite of limitations, the computer does have extensive potential for individualizing instruction. The design of the instructional materials produced in this study may well provide a model for the design of other simulated experiments which will be effective supplements to science curricula.

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

PROGRAM AND FILE LISTINGS

technical report 1

```
list
FORCEA

10  PRINT ""
20  FILES LUNF1
30  DIM A$[64],N[14,10]
40  MAT N=ZER
50  L=0
60  PRINT "WELCOME TO OUR SIMULATED PHYSICS LAB. THROUGH THIS SERIES OF"
70  PRINT "PROGRAMS AND FILM LOOPS WE WILL INVESTIGATE HOW"
80  PRINT "FORCE AFFECTS THE MOTION OF AN OBJECT."
90  PRINT "HAVE YOU WATCHED THE FILM LOOP FORCE & MOTION I?"
100  PRINT
110  PRINT "USE ONLY NUMERALS AND CAPS FOR ANSWERS"
120  PRINT
130  INPUT A$
140  Z=1
150  GOSUB 1350
160  READ #1,1
170  FOR I=1 TO 13
180  READ #1;A$
190  PRINT A$
200  NEXT I
210  PRINT "IF A ROCK IS TRAVELLING THROUGH SPACE AT 100 M/SEC AND THERE ARE NO"
220  PRINT "FORCES ACTING ON IT, WHAT WILL BE ITS SPEED (IN M/SEC) 5 SEC. LATER?"
230  INPUT D
240  IF D#100 THEN 1520
250  READ #1,14
260  FOR I=1 TO 9
270  READ #1;A$
280  PRINT A$
290  NEXT I
300  PRINT "TYPE BELOW THE AMOUNT OF STRETCH IN CM WHICH YOU INTEND TO APPLY DURING"
310  PRINT "THE RUNS THROUGHOUT THIS EXPERIMENT."
320  INPUT B
330  IF B<50 THEN 2570
340  IF B>100 THEN 2600
350  PRINT "YOU MAKE THE SIMULATED RUN WITH THE CART APPLYING A FORCE OF";B;"CM,"
360  PRINT "THEN I'LL ANALYZE THE TICKER TAPE, MAKE A DATA TABLE, AND PLOT A GRAPH"
370  PRINT "OF VELOCITY VERSUS TIME."
380  PRINT "HOW MANY BRICKS SHALL WE PLACE ON THE CART FOR A LOAD IN THIS RUN?"
390  INPUT C
400  IF C<1 THEN 2470
410  IF C>9 THEN 2530
420  IF C=INT(C) THEN 450
430  PRINT "WE DON'T HAVE PARTIAL BRICKS IN OUR LAB. TYPE IN A WHOLE NUMBER!"
440  GOTO 390
450  GOSUB 1030
460  PRINT "WHAT KIND OF RELATIONSHIP EXISTS BETWEEN VELOCITY AND TIME UNDER THESE"
470  PRINT "CONDITIONS (DIRECT OR INVERSE)?"
480  INPUT A$
490  IF A$#"DIRECT" THEN 2370
500  READ #1,23
510  FOR I=1 TO 11
520  READ #1;A$
530  PRINT A$
540  NEXT I
```

```
550  PRINT "FROM THE GRAPH WE CAN SEE THAT THE CONSTANT FORCE GAVE OUR"
560  PRINT "CART WHAT KIND OF ACCELERATION?"
570  INPUT A$
580  PRINT
590  IF A$#"CONSTANT" THEN 1700
600  LET L=0
610  GOSUB 1260
620  PRINT "BUT IS THE ACCELERATION ALWAYS CONSTANT UNDER THE INFLUENCE OF A"
630  PRINT "CONSTANT FORCE?"
640  PRINT "HOW WOULD THE DATA DIFFER IF WE HAD USED A DIFFERENT LOAD?"
650  PRINT "TO FIND OUT, LET'S CHANGE THE NUMBER OF BRICKS ON THE CART AND MAKE"
660  PRINT "ANOTHER RUN APPLYING THE SAME FORCE OF";B;" CM."
670  PRINT "HOW MANY BRICKS SHALL WE PLACE ON THE CART FOR A LOAD IN THIS RUN?"
680  LET I=2
690  INPUT D
700  IF D<1 THEN 2470
710  IF D>9 THEN 2530
720  IF D=C THEN 2130
730  IF D=INT(D) THEN 760
740  PRINT "WE DON'T HAVE PARTIAL BRICKS IN OUR LAB. TYPE IN A WHOLE NUMBER!"
750  GOTO 690
760  LET C=D
770  MAT N=ZER
780  GOSUB 1030
790  GOSUB 1260
800  PRINT "AS YOU CAN SEE OUR DATA ALSO INDICATE THAT THE MASS OF THE CART DID"
810  PRINT "AFFECT THE ACCELERATION."
820  PRINT "WAS THE ACCELERATION GREATER OR SMALLER WHEN THE SMALLER MASS WAS"
830  PRINT "ACCELERATED?"
840  INPUT A$
850  IF A$#"GREATER" THEN 1950
860  READ #1,34
870  FOR I=1 TO 9
880  READ #1;A$
890  PRINT A$
900  NEXT I
910  LET L=0
920  PRINT "IF AN AIRPLANE'S ENGINES PRODUCE A NET FORCE WHICH IS CONSTANT AND WHICH
930  PRINT "ACCELERATES THE PLANE FROM 0 TO 100 M/SEC IN 20 SEC, WHAT WILL BE THE"
940  PRINT "PLANE'S VELOCITY IN M/SEC AT THE END OF 40 SEC?"
950  INPUT D
960  IF D#200 THEN 2020
970  PRINT "RIGHT! AGAIN, A CONSTANT FORCE CAUSES A MASS TO HAVE A CONSTANT"
980  PRINT "ACCELERATION."
990  PRINT "BUT HOW WOULD THE ACCELERATION HAVE DIFFERED HAD WE APPLIED A DIFFERENT"
1000  PRINT "FORCE?--THIS QUESTION WILL FORM THE BASIS FOR THE NEXT"
1010  PRINT "EXPERIMENT IN THIS SERIES."
1020  GOTO 2640
1030  PRINT "I'VE GOT THE BUZZER ON; --- AND THERE YOU GO PUSHING THE CART DOWN THE"
1040  PRINT "HALL FLEET-FOOTED AS A DEER!! ??"
1050  LET A=4*B/((C+1)*5)
1060  LET A=INT(10*A)/10
1070  PRINT "HERE IS A DATA TABLE I'VE MADE FROM THE TICKER TAPE PULLED BY THE"
1080  PRINT "CART IN THIS RUN:"
1090  PRINT
1100  PRINT "TIME (SEC)  VELOCITY (CM/SEC)  [LOAD =";C;" BRICKS  FORCE =";B;" CM]"
1110  FOR T=.1 TO 1 STEP .1
```

```
1120  PRINT TAB(3);T;TAB(16);A*T
1130  LET V=A*T+1
1140  IF V<13.5 THEN 1160
1150  LET V=14
1160  LET N[V,T*10]=1
1170  NEXT T
1180  PRINT
1190  PRINT "HERE IS A GRAPH OF THE DATA:"
1200  GOSUB 2160
1210  PRINT "STUDY THE DATA AND GRAPH. CAN YOU OBSERVE ANY REGULARITIES?"
1220  INPUT A$
1230  Z=2
1240  GOSUB 1350
1250  RETURN
1260  PRINT "THE CONSTANT FORCE WE APPLIED IN THIS RUN DID PRODUCE A CONSTANT"
1270  PRINT "ACCELERATION."
1280  PRINT "ANALYZE THE GRAPH AND DETERMINE THE ACCELERATION IN CM/SEC/SEC."
1290  INPUT D
1300  IF (D >= A+.5) OR (D <= A-.5) THEN 1790
1310  PRINT "OK.  OUR CONSTANT FORCE OF";B;"CM CAUSED OUR CART TO HAVE A CONSTANT"
1320  PRINT "ACCELERATION OF";A;" CM/SEC/SEC."
1330  PRINT
1340  RETURN
1350  IF A$="YES" THEN 1410
1360  IF A$="yes" THEN 1410
1370  IF A$="no" THEN 1470
1380  IF A$="NO" THEN 1470
1390  PRINT "PLEASE TYPE YES OR NO"
1400  GOTO Z OF 90,1210
1410  GOTO Z OF 160,1250
1420  PRINT "CALL PROCTOR - ERROR IN LINE 1296"
1430  GOTO 2690
1440  RETURN
1450  PRINT "PLEASE TYPE IN 'YES' OR 'NO'; I'LL ASK THE QUESTION AGAIN."
1460  GOTO 90
1470  IF Z=2 THEN 1670
1480  PRINT "TO MAKE THE SIMULATION AS REALISTIC AS POSSIBLE YOU SHOULD VIEW FILM"
1490  PRINT "LOOP FORCE & MOTION I PRIOR TO PROCEEDING. THE FILM WILL HELP YOU"
1500  PRINT "UNDERSTAND THE NATURE OF THE APPARATUS WE WILL USE."
1510  GOTO 2690
1520  IF D#0 THEN 1550
1530  PRINT "BE CAREFUL TO TYPE NUMBERS - TRY AGAIN"
1540  GOTO 230
1550  LET L=L+1
1560  IF L=2 THEN 1630
1570  READ #1,43
1580  FOR I=1 TO 6
1590  READ #1;A$
1600  PRINT A$
1610  NEXT I
1620  GOTO 210
1630  PRINT "NO; APPARENTLY YOU NEED TO REVIEW THE PROPERTY OF INERTIA (NEWTON'S 1ST"
1640  PRINT "LAW) BEFORE CONTINUING. CONSULT YOUR TEACHER OR YOUR TEXT AS SOON AS"
1650  PRINT "POSSIBLE."
1660  GOTO 2690
1670  PRINT "LOOK AT THE GRAPH AGAIN. THE PLOTTED POINTS SHOW THAT AS TIME INCREASED"
```

```
1680  PRINT "THE VELOCITY INCREASED IN A RATHER SIMPLE MANNER."
1690  GOTO 1250
1700  IF A$="constant" THEN 600
1710  IF A$="UNIFORM" THEN 600
1720  IF A$="uniform" THEN 600
1730  READ #1,49
1740  FOR I=1 TO 8
1750  READ #1;A$
1760  PRINT A$
1770  NEXT I
1780  GOTO 550
1790  LET L=L+1
1800  IF L >= 3 THEN 1920
1810  IF L=2 THEN 1860
1820  PRINT "SORRY, YOUR CALCULATION IS INCORRECT.  I'LL GIVE YOU ANOTHER CHANCE."
1830  PRINT "REMEMBER ACCELERATION IS THE SLOPE OF THE VELOCITY V.TIME GRAPH;"
1840  PRINT "SLOPE = RISE/RUN = CHANGE IN V/CHANGE IN T."
1850  GOTO 1280
1860  PRINT "YOU'RE NOT MEASURING THE SLOPE PROPERLY. STUDY THE GRAPH AND CALCULATE"
1870  PRINT "A AGAIN. IT SHOULD EQUAL";A;"CM/SEC/SEC. TYPE 'GO' IF YOU SEE HOW TO GE
1880  PRINT "THIS AND YOU WANT TO RETURN TO THE EXPERIMENT, OTHERWISE TYPE 'HELP'."
1890  INPUT A$
1900  IF A$="GO" THEN 1340
1910  IF A$="go" THEN 1340
1920  PRINT "YOU NEED ASSISTANCE IN MEASURING THE SLOPE OF A STRAIGHT"
1930  PRINT "LINE.  SEE YOUR TEACHER FOR HELP BEFORE RETURNING TO THIS PROGRAM."
1940  GOTO 2690
1950  IF A$="LARGER" THEN 860
1960  IF A$="greater" THEN 860
1970  IF A$="larger" THEN 860
1980  PRINT "NO. LOOK AT YOUR GRAPHS AGAIN. THE ACCELERATIONS ARE REPRESENTED BY THE
1990  PRINT "SLOPES OF THE VELOCITY V. TIME GRAPHS. THE LARGER MASS HAS THE SMALLER"
2000  PRINT "ACCELERATION! LET'S TRY THE QUESTION AGAIN."
2010  GOTO 820
2020  IF L >= 2 THEN 2100
2030  LET L=L+1
2040  PRINT "NO. SINCE A CONSTANT NET FORCE IS PRESENT THE PLANE WILL UNDERGO A"
2050  PRINT "CONSTANT ACCELERATION. THE SAME CHANGE IN VELOCITY WILL OCCUR IN EACH"
2060  PRINT "TIME INTERVAL.FROM THE DATA IN THE PROBLEM WE CAN SEE THAT THE PLANE'S"
2070  PRINT "VELOCITY INCREASES BY 5M/SEC EACH SEC.WHILE THE NET FORCE IS PRESENT."
2080  PRINT "LET'S TRY THE QUESTION AGAIN."
2090  GOTO 920
2100  PRINT "NO. THE CORRECT ANSWER IS 200M/SEC. IF YOU DON'T UNDERSTAND WHY DISCUSS
2110  PRINT "THIS WITH YOUR TEACHER AS SOON AS POSSIBLE."
2120  GOTO 990
2130  PRINT "NO; DON'T USE";D;" BRICKS AGAIN.  WE WANT TO MAKE A RUN WITH A LOAD"
2140  PRINT "THAT IS DIFFERENT FROM OUR FIRST RUN. SO, AGAIN--"
2150  GOTO 670
2160  PRINT
2170  FOR Y=12 TO 1 STEP -1
2180  READ A$
2190  PRINT A$;
2200  IF Y/2#INT(Y/2) THEN 2220
2210  PRINT TAB(7);Y;
2220  FOR X=1 TO 10
2230  IF N[Y+1,X]=1 THEN 2270
```

```
2240  NEXT X
2250  PRINT TAB(13);"+"
2260  GOTO 2280
2270  PRINT TAB(13);"+";TAB(13+X*4);"X"
2280  NEXT Y
2290  PRINT TAB(8);"0    + + + + + + + + + + + + + + + + + + + + + +"
2300  PRINT TAB(13);"0  .1  .2  .3  .4  .5  .6  .7  .8  .9  1.0"
2310  PRINT TAB(26);"TIME (SEC)"
2320  PRINT "(LOAD =";C;" BRICKS   FORCE =";B;" CM)"
2330  PRINT
2340  DATA "","","V","E","L","O  (CM/SEC)","C","I","T","Y","",""
2350  RESTORE
2360  RETURN
2370  IF A$="direct" THEN 500
2380  IF A$="INVERSE" THEN 2420
2390  IF A$="inverse" THEN 2420
2400  PRINT "YOUR ANSWER MUST BE 'DIRECT' OR 'INVERSE'.  SO, AGAIN--"
2410  GOTO 460
2420  PRINT "WRONG. WHEN TWO VARIABLES ARE INVERSELY RELATED ONE DECREASES AS THE"
2430  PRINT "OTHER INCREASES. LOOK AT YOUR GRAPH AGAIN. IT SHOWS THAT THE VELOCITY"
2440  PRINT "INCREASED WHILE TIME INCREASED. THIS MEANS THAT THE VARIABLES ARE"
2450  PRINT "DIRECTLY RELATED. SO, AGAIN--"
2460  GOTO 460
2470  PRINT "IF YOUR CART HAS LESS THAN 1 BRICK ON IT AND YOU APPLY THE FORCES"
2480  PRINT "AVAILABLE WITH OUR APPARATUS, THE CART WILL TAKE OFF SO FAST YOU WON'T"
2490  PRINT "BE ABLE TO APPLY A CONSTANT FORCE. I SUGGEST A LOAD OF 1 OR MORE BRICKS.^
2500  PRINT "SO, AGAIN--"
2510  IF I=2 THEN 690
2520  GOTO 390
2530  PRINT "I CAN ONLY FIND NINE BRICKS IN THE LABORATORY. BESIDES, THE CART WILL"
2540  PRINT "BE PRETTY HARD TO HANDLE WITH MORE THAN NINE BRICKS ON IT. SO, AGAIN--"
2550  IF I=2 THEN 690
2560  GOTO 390
2570  PRINT "THE UNSTRETCHED RUBBER LOOP IS ALMOST 50 CM LONG.  WHEN WE STRETCH THE"
2580  PRINT "LOOP LESS THAN 50 CM WE'RE NOT APPLYING A SIGNIFICANT FORCE.SO, AGAIN--"
2590  GOTO 300
2600  PRINT "WE'RE STRETCHING THE RUBBER BAND WITH A METER STICK WHICH IS"
2610  PRINT "100CM LONG.  YOU CAN'T APPLY A CONSTANT FORCE ACCURATELY WITH"
2620  PRINT "THESE MATERIALS IF THE STRETCH EXCEEDS 100CM. SO, AGAIN---"
2630  GOTO 300
2640  READ #1,57
2650  FOR I=1 TO 14
2660  READ #1;A$
2670  PRINT A$
2680  NEXT I
2690  PRINT "TO SIGN OFF THE TERMINAL, TYPE 'BYE' AND PRESS THE RETURN KEY"
2700  END
```

ONE INSTRUCTION BEFORE WE BEGIN: WHEN YOU'RE ASKED TO TYPE IN NUMERICAL DATA, DO NOT TYPE THE UNITS OF THE ANSWER. FOR EXAMPLE, AN ANSWER OF 10M/SEC SHOULD BE TYPED '10'.

EXPERIENCE TELLS US THAT WE MUST APPLY A FORCE TO CAUSE AN OBJECT TO MOVE. IN THIS SERIES OF SIMULATED EXPERIMENTS WE SHALL INVESTIGATE PHYSICAL VARIABLES WHICH AFFECT THE MOTION OF AN OBJECT. THE DATA WHICH WE WILL GENERATE WILL BE VERY SIMILAR TO THAT OBTAINED BY EXPERIMENTERS USING THE REAL APPARATUS SHOWN IN THE FILM LOOP. I WILL BE YOUR LAB PARTNER.

BEFORE WE CONTINUE, YOU SHOULD BE FAMILIAR WITH THE PROPERTY OF INERTIA WHICH WAS DESCRIBED BY GALILEO AND NEWTON.

CORRECT! DUE TO THE PROPERTY OF INERTIA (SOMETIMES CALLED NEWTON'S 1ST LAW) AN OBJECT'S VELOCITY WILL BE CONSTANT UNTIL AN UNBALANCED FORCE IS APPLIED. YET, IN WHAT WAY WILL AN UNBALANCED FORCE CAUSE THE VELOCITY TO CHANGE?

IN THIS FIRST EXPERIMENT WE SHALL INVESTIGATE HOW AN OBJECT'S VELOCITY CHANGES WHEN WE APPLY A CONSTANT FORCE. WE SHALL APPLY A CONSTANT FORCE TO THE CART BY KEEPING ONE LOOP OF RUBBER STRETCHED A CONSTANT LENGTH. (WE CAN STRETCH OUR LOOP TO ANY LENGTH BETWEEN 50CM AND 100CM.)

RIGHT! IN FACT, THERE APPEARS TO BE A LINEAR RELATIONSHIP BETWEEN VELOCITY AND TIME IF WE OVERLOOK THE SMALL IRREGU-

LARITIES PROBABLY CAUSED BY EXPERIMENTAL ERROR -- SUCH AS VARIATIONS IN THE FORCE APPLIED. THE CHANGE IN VELOCITY WAS PROPORTIONAL TO THE TIME INTERVAL DURING WHICH THE FORCE ACTED. WHEN WE APPLIED A CONSTANT FORCE TO THE CART THE VELOCITY INCREASED AT A CONSTANT RATE. FROM YOUR STUDY OF MOTION YOU WILL RECALL THAT ACCELERATION IS THE RATE OF CHANGE OF VELOCITY. THE ACCELERATION OF AN OBJECT IS THEN THE SLOPE OF ITS VELOCITY V. TIME GRAPH. (CHANGE IN V/CHANGE IN T).

CORRECT; THE SMALLER MASS UNDERWENT A LARGER ACCELERATION. APPARENTLY THERE IS SOME KIND OF INVERSE RELATIONSHIP BETWEEN THE MASS OF AN OBJECT AND ITS ACCELERATION WHEN A CONSTANT FORCE IS APPLIED. WE WILL FURTHER INVESTIGATE THIS RELATIONSHIP IN THE THIRD EXPERIMENT IN THIS SERIES. TO SUMMARIZE: WE CAN SEE FROM THE GRAPHS OF OUR DATA THAT WHEN A CONSTANT FORCE WAS APPLIED TO A CART WITH A PARTICULAR MASS THE ACCELERATION WAS CONSTANT.

NOW, LET'S TRY ONE LAST PROBLEM.

NO; YOUR ANSWER IS INCORRECT. BY THE PROPERTY OF INERTIA WE MEAN THAT AN UNBALANCED FORCE IS NECESSARY TO CHANGE THE VELOCITY OF AN OBJECT. IN THIS PROBLEM WE WERE TOLD THAT NO FORCES WERE ACTING, AND HENCE, NO CHANGE IN VELOCITY WILL OCCUR. APPARENTLY EVEN FRICTION IS NEGLIGIBLE IN THIS PROBLEM. I'LL ASK THE QUESTION ONE MORE TIME.

INCORRECT. THIS GRAPH OF VELOCITY VS. TIME CAN BE REPRESENTED BY A STRAIGHT LINE. THE SLOPE OF A STRAIGHT LINE IS THE SAME

AT ALL POINTS ON THE LINE. AN OBJECT'S ACCELERATION IS ITS CHANGE IN VELOCITY PER UNIT TIME; IT IS THE SLOPE OF THE VELOCITY V. TIME GRAPH. THEREFORE THE CONSTANT FORCE HAS CAUSED A CONSTANT ACCELERATION. IF YOU HAVE DIFFICULTY UNDERSTANDING THESE IDEAS, DO TALK THEM OVER WITH YOUR TEACHER AS SOON AS POSSIBLE. LET'S TRY THE QUESTION AGAIN--

SINCE YOU HAVE BEEN STUDYING FORCE AND MOTION USING A SIMULATED EXPERIMENT, YOU HAVE NOT HAD TO COPE WITH THE MANY SOURCES OF EXPERIMENTAL ERROR PRESENT IN THE ACTUAL APPARATUS. IF YOU WERE TO DO THE REAL EXPERIMENT YOU WOULD HAVE TO REDUCE SUCH ERROR BEFORE THE GENERALIZATIONS WE'VE SEEN COULD BE OBSERVED. PERHAPS YOU WILL BE ABLE TO PURSUE THE INVESTIGATION FURTHER AT HOME OR IN YOUR LAB. AFTER YOU'VE SIGNED OFF THE TERMINAL ROLL OUT SEVERAL EXTRA INCHES OF PAPER. ON THIS PAPER LIST THE SOURCES OF EXPERIMENTAL ERROR AS YOU ENVISION THEM AND STATE THE MAJOR CONCLUSIONS YOU CAN DRAW FROM THE EXPERIMENT. INCLUDE THIS PAPER IN YOUR PHYSICS NOTEBOOK. AS SOON AS YOU HAVE THE OPPORTUNITY VIEW THE NEXT FILM LOOP 'FORCE & MOTION II' AND THEN RUN 'FORCEB'.

```
list
FORCEB

10  FILES LUNF2
20  DIM A$[65],N[11,10],O[11,10]
30  PRINT "WELCOME AGAIN TO OUR SIMULATED PHYSICS LAB. IN THIS SECOND"
40  PRINT "EXPERIMENT OF THE SERIES WE WILL INVESTIGATE HOW FORCES AFFECT"
50  PRINT "THE ACCELERATION OF AN OBJECT. HAVE YOU COMPLETED FORCEA &"
60  PRINT "WATCHED THE FILM LOOP 'FORCE & MOTION II'?"
70  INPUT A$
80  IF A$="YES" THEN 90
82  IF A$#"yes" THEN 2760
90  LET L=0
95  MAT N=ZER
96  MAT O=ZER
100  PRINT "IN OUR LAST EXPERIMENT WE OBSERVED THAT A CONSTANT FORCE GAVE OUR CART"
110  PRINT "WHAT KIND OF ACCELERATION?"
120  INPUT A$
130  IF A$="CONSTANT" THEN 150
132  IF A$="constant" THEN 150
134  IF A$="uniform" THEN 150
140  IF A$#"UNIFORM" THEN 2800
150  PRINT "RIGHT! NOW TO STUDY HOW ACCELERATION VARIES WHEN THE APPLIED FORCE IS"
160  PRINT "CHANGED WE'LL HOLD ALL OTHER VARIABLES (SUCH AS MASS) CONSTANT."
```

```
170  PRINT "HOW MANY BRICKS SHALL WE PLACE ON THE CART THROUGHOUT THIS EXPERIMENT?"
180  INPUT C
190  IF C<2 THEN 2660
200  IF C>10 THEN 2720
210  LET M=(C+1)*5
220  LET F=2.5
230  IF C>9 THEN 310
240  LET F=2
250  IF C>7 THEN 310
260  LET F=1.5
270  IF C>5 THEN 310
280  LET F=1
290  IF C>3 THEN 310
300  LET F=.5
310  READ #1,1
320  FOR I=1 TO 7
330  READ #1;A$
340  PRINT A$
350  NEXT I
360  FOR L=1 TO 11
370  PRINT "HOW MANY LOOPS ARE YOU APPLYING IN THIS RUN?"
380  INPUT B
390  IF B=INT(B) THEN 420
400  PRINT "WE DON'T HAVE ANY PARTIAL LOOPS IN OUR LAB. TYPE IN A WHOLE NUMBER."
410  GOTO 380
420  IF B<0 THEN 1470
430  IF B>10 THEN 1500
440  LET A1=240*(B-F)/M
450  LET A1=INT(10*A1+.5)/10
460  LET A2=240*B/M
470  LET A2=INT(10*A2+.5)/10
480  IF A1>0 THEN 500
490  LET A1=0
500  PRINT "THE ACCELERATION IN THIS RUN WAS:";A1;" CM/SEC/SEC."
510  IF A2 >= 105 THEN 560
520  IF A1 >= 105 THEN 560
530  IF B=0 THEN 560
540  LET N(A1/10+1,B)=1
550  LET O(A2/10+1,B)=1
560  IF L<5 THEN 620
570  PRINT "IF YOU'D LIKE TO MAKE ANOTHER RUN, TYPE 'RUN'; IF YOU'D LIKE ME"
580  PRINT "TO GRAPH A VS. F, TYPE 'PLOT'."
590  INPUT A$
595  IF A$="plot" THEN 630
600  IF A$="PLOT" THEN 630
605  IF A$="run" THEN 620
610  IF A$#"RUN" THEN 1540
620  NEXT L
630  GOSUB 2180
640  PRINT "CAN YOU OBSERVE ANY REGULARITIES IN THIS GRAPH?"
650  INPUT A$
655  IF A$="yes" THEN 670
660  IF A$#"YES" THEN 1560
```

```
670  PRINT "WHAT KIND OF RELATIONSHIP EXISTS BETWEEN ACCELERATION AND FORCE "
680  PRINT "(DIRECT OR INVERSE)?"
690  INPUT A$
695  IF A$="direct" THEN 710
700  IF A$#"DIRECT" THEN 2570
710  READ #1,8
720  FOR I=1 TO 6
730  READ #1;A$
740  PRINT A$
750  NEXT I
760  INPUT A$
770  LET L=0
780  PRINT "THERE IS FRICTION BETWEEN THE CART AND THE FLOOR WHICH OPPOSES THE"
790  PRINT "FORCE WE APPLY. STUDY THE GRAPH & DETERMINE THE FORCE OF"
800  PRINT "FRICTION(IN LOOPS)."
810  INPUT D
820  IF D<(F-.5) THEN 1620
830  IF D>(F+.5) THEN 1620
840  READ #1,15
850  FOR I=1 TO 5
860  READ #1;A$
870  PRINT A$
880  NEXT I
890  INPUT A$
895  IF A$="left" THEN 1750
900  IF A$="LEFT" THEN 1750
905  IF A$="right" THEN 920
910  IF A$#"RIGHT" THEN 1810
920  READ #1,20
930  FOR I=1 TO 4
940  READ #1;A$
950  PRINT A$
960  NEXT I
970  LET L=0
980  PRINT "TYPE IN THE POINT WHERE YOU THINK THE NEW PLOT WILL INTERSECT THE"
990  PRINT "FORCE AXIS."
1000  INPUT D
1010  IF D#0 THEN 1830
1020  PRINT "RIGHT! HERE'S THE NEW GRAPH:"
1030  MAT N=O
1040  GOsUB 2180
1050  PRINT "AGAIN, WE SEE A LINEAR RELATIONSHIP BETWEEN FORCE AND ACCELE-"
1060  PRINT "RATION. NOTE THAT THOUGH THE INTERCEPT WITH THE FORCE AXIS"
1070  PRINT "HAS BEEN MOVED, THE SLOPE OF THE GRAPH HAS NOT CHANGED. "
1080  PRINT "FRICTIONAL FORCE DOES NOT APPEAR TO AFFECT THE SLOPE OF THE"
1090  PRINT "ACCEL. VS. FORCE GRAPH."
1100  LET L=0
1110  PRINT "WRITE AN EQUATION TO FIT THIS GRAPH. USE 'A' TO REPRESENT ACCELERATION"
1120  PRINT "AND 'F' TO REPRESENT FORCE. USE 'K' TO REPRESENT THE SLOPE (DON'T"
1130  PRINT "BOTHER TO CALCULATE IT). BEGIN THE EQUATION:  A=  ..."
1140  INPUT A$
1145  IF A$="a=kf" THEN 1160
1150  IF A$#"A=KF" THEN 2400
```

```
1160  PRINT "RIGHT!--BUT WHAT FACTORS WILL CAUSE THE SLOPE TO CHANGE?  WE'VE"
1170  PRINT "OBSERVED THAT FRICTION HAS NO EFFECT. WHAT OTHER VARIABLE"
1180  PRINT "MIGHT CAUSE THE SLOPE TO CHANGE?"
1190  INPUT A$
1195  IF A$="mass" THEN 1210
1200  IF A$#"MASS" THEN 1930
1210  READ #1,24
1220  FOR I=1 TO 10
1230  READ #1;A$
1240  PRINT A$
1250  NEXT I
1260  LET L=0
1270  PRINT "A SPACESHIP IS ACCELERATING IN SPACE AT 10M/SEC/SEC DUE TO THE FORCE"
1280  PRINT "PROVIDED BY ONE ROCKET ENGINE. SUDDENLY 2 MORE IDENTICAL ROCKETS ARE"
1290  PRINT "IGNITED PROVIDING THRUST IN THE SAME DIRECTION AS THE FIRST. WHAT"
1300  PRINT "ACCELERATION IN M/SEC/SEC DOES THE SHIP NOW EXPERIENCE?"
1310  INPUT D
1320  IF D#30 THEN 1950
1330  PRINT "GOOD! HERE'S ANOTHER PROBLEM FOR YOU TO TRY:"
1340  PRINT "IN 10 SEC AN OBJECT ACCELERATES FROM REST TO A SPEED OF 300CM/SEC"
1350  PRINT "WHEN ACTED UPON BY A NET FORCE(F). AT THE END OF THE 10SEC"
1360  PRINT "INTERVAL F BECOMES ONE-THIRD ITS ORIGINAL STRENGTH."
1370  PRINT "WHAT IS THE SPEED OF THE OBJECT AT THE END OF THE FIRST 20 SEC IN"
1380  PRINT "CM/SEC?"
1390  INPUT D
1400  IF D#400 THEN 2060
1410  READ #1,34
1420  FOR I=1 TO 11
1430  READ #1;A$
1440  PRINT A$
1450  NEXT I
1460  GOTO 2880
1470  PRINT "A NEGATIVE NUMBER OF LOOPS?? WE CAN ONLY APPLY POSITIVE"
1480  PRINT "FORCE WITH OUR APPARATUS. SO, AGAIN --"
1490  GOTO 370
1500  PRINT "WITH MORE THAN 10 LOOPS STRETCHED 60CM THE CART MOVES SO FAST"
1510  PRINT "YOU CAN'T APPLY A CONSTANT FORCE. DON'T USE MORE THAN 10"
1520  PRINT "LOOPS. SO, AGAIN --"
1530  GOTO 370
1540  PRINT "YOU DIDN'T TYPE 'PLOT' OR 'RUN'. WHICH DO YOU WANT TO DO?"
1550  GOTO 590
1560  PRINT "ARE YOU LOOKING CAREFULLY AT THE DATA?"
1570  PRINT "NOTICE THAT AS FORCE INCREASES, ACCELERATION"
1580  PRINT "ALSO INCREASES."
1610  GOTO 670
1620  IF L>1 THEN 1690
1630  LET L=L+1
1640  PRINT "SORRY, WRONG ANSWER. THE FORCES WE HAVE PLOTTED ARE THE FORCES"
1650  PRINT "WE APPLIED. FRICTION OPPOSES THE APPLIED FORCE. UNTIL THE"
1660  PRINT "APPLIED FORCE EXCEEDS FRICTION THERE WILL BE NO ACCELERATION."
1670  PRINT "FIND THAT POINT ON YOUR GRAPH. LET'S TRY THE QUESTION AGAIN."
1680  GOTO 810
1690  PRINT "NO. THE FRICTIONAL FORCE IS";F;" LOOPS. IT IS REPRESENTED"
1700  PRINT "BY THE INTERCEPT OF THE GRAPH WITH THE FORCE AXIS. IF YOU"
```

```
1710  PRINT "DON'T UNDERSTAND DISCUSS THIS WITH YOUR TEACHER AS SOON"
1720  PRINT "AS POSSIBLE. NOW, ANSWER THE QUESTION CORRECTLY. WHAT IS THE FORCE OF"
1730  PRINT "FRICTION SHOWN ON THE GRAPH?"
1740  GOTO 810
1750  PRINT "THINK IT THROUGH AGAIN.  THE"
1760  PRINT "MORE FRICTION, THE MORE FORCE"
1770  PRINT "REQUIRED TO CHANGE THE INTERCEPT."
1771  READ #1,17
1772  FOR I=1 TO 3
1773  READ #1;A$
1774  PRINT A$
1775  NEXT I
1800  GOTO 890
1610  PRINT "YOUR ANSWER MUST BE 'LEFT' OR 'RIGHT'. SO AGAIN --"
1820  GOTO 890
1830  IF L>1 THEN 1890
1840  LET L=L+1
1850  PRINT "NO. PLOTTING THE RESULTANT FORCE IS EQUIVALENT TO SUBTRACTING"
1860  PRINT "THE FRICTIONAL FORCE FROM THE APPLIED FORCE. THE GRAPH WILL"
1870  PRINT "REPRESENT A FRICTIONLESS CONDITION. TRY THE QUESTION AGAIN."
1880  GOTO 980
1890  PRINT "NO.  THE NEW GRAPH SHOULD PASS THROUGH THE ORIGIN. IF YOU DON'T"
1900  PRINT "UNDERSTAND WHY. DISCUSS THIS WITH YOUR TEACHER AS SOON AS "
1910  PRINT "POSSIBLE. HERE'S THE NEW GRAPH."
1920  GOTO 1040
1930  PRINT "WHAT ABOUT THE MASS OF THE CART?"
1940  GOTO 1210
1950  IF L>1 THEN 2010
1960  LET L=L+1
1970  PRINT "WRONG. THE APPLIED FORCE INCREASED TO 3 TIMES ITS ORIGINAL"
1980  PRINT "VALUE. THE ACCELERATION OF THE SPACESHIP IS PROPORTIONAL TO"
1990  PRINT "THE APPLIED FORCE. TRY THE QUESTION AGAIN."
2000  GOTO 1270
2010  PRINT "SINCE THE FORCE INCREASED TO 3 TIMES ITS ORIGINAL VALUE, THE"
2020  PRINT "ACCEL. INCREASED TO 3 TIMES ITS ORIGINAL VALUE, AND 3X10=30."
2030  PRINT "IF YOU DON'T UNDERSTAND DISCUSS THIS WITH YOUR TEACHER AS SOON"
2040  PRINT "AS POSSIBLE. NOW, HERE'S ANOTHER PROBLEM."
2050  GOTO 1340
2060  IF L>2 THEN 2140
2070  LET L=L+1
2080  PRINT "SORRY, WRONG ANSWER, IN THE SECOND TIME INTERVAL THE FORCE"
2090  PRINT "IS 1/3 ITS ORIGINAL VALUE AND HENCE THE ACCEL. IS 1/3 ITS"
2100  PRINT "ORIGINAL VALUE. IF THE OBJECT GAINED 300CM/SEC IN THE FIRST"
2110  PRINT "10 SEC, IT WILL GAIN 1/3 THAT IN THE NEXT 10 SEC. TRY THE"
2120  PRINT "QUESTION AGAIN."
2130  GOTO 1370
2140  PRINT "NO.  1/3 OF 300 IS 100.  YOU NEED FURTHER HELP IN UNDERSTANDING"
2150  PRINT "THIS CONCEPT. CONSULT YOUR TEACHER BEFORE CONTINUING THIS"
2160  PRINT "PROGRAM."
2170  GOTO 2860
2180  PRINT
2190  FOR Y=10 TO 1 STEP -1
2200  READ A$
2210  PRINT A$;
```

```
2220  IF Y/2#INT(Y/2) THEN 2270
2230  IF Y#10 THEN 2260
2240  PRINT TAB(6);" "10*Y;
2250  GOTO 2270
2260  PRINT TAB(7);10*Y;
2270  FOR X=1 TO 10
2280  IF N[Y+1,X]=1 THEN 2320
2290  NEXT X
2300  PRINT TAB(13);"+"
2310  GOTO 2330
2320  PRINT TAB(13);"+";TAB(13+X*4);"X"
2330  NEXT Y
2340  PRINT TAB(9);"0   + + + + + + + + + + + + + + + + + + + + + +"
2350  PRINT TAB(13);"0   1   2   3   4   5   6   7   8   9  10"
2360  PRINT TAB(29);"FORCE (LOOPS)"
2370  DATA "","","A","C","C","E(CM/SEC/SEC)","L.","","",""
2380  RESTORE
2390  RETURN
2400  IF A$="A=K*F" THEN 1160
2405  IF A$="a=K*f" THEN 1160
2410  IF A$="A=FK" THEN 1160
2415  IF A$="a=fK" THEN 1160
2420  IF A$="A=KXF" THEN 1160
2425  IF A$="a=kxf" THEN 1160
2430  IF A$="A=FXK" THEN 1160
2435  IF A$="a=fxK" THEN 1160
2440  IF A$="A=F*K" THEN 1160
2445  IF A$="a=f*K" THEN 1160
2450  IF L>1 THEN 2530
2460  LET L=L+1
2470  READ #1,45
2480  FOR I=1 TO 7
2490  READ #1;A$
2500  PRINT A$
2510  NEXT I
2520  GOTO 1110
2530  PRINT "NO.  THE EQUATION IS:  A=KF.  IF YOU DON'T UNDERSTAND"
2540  PRINT "WHY DIsCUSS THIS WITH YOUR TEACHER AS SOON AS POSSIBLE."
2550  PRINT "NOW, HERE'S THE QUESTION ONCE MORE."
2560  GOTO 1110
2570  IF A$="INVERSE" THEN 2600
2575  IF A$="inverse" THEN 2600
2580  PRINT "YOUR ANSWER MUST BE 'DIRECT' OR 'INVERSE'. SO, AGAIN --"
2590  GOTO 670
2600  READ #1,24
2610  FOR I=1 TO 4
2620  READ #1;A$
2630  PRINT A$
2640  NEXT I
2650  GOTO 670
2660  PRINT "THE EXPERIMENT MUST HAVE AT LEAST 2"
2670  PRINT "BRICKS ON THE CART."
2680  PRINT "SO, I'LL NEED ANOTHER NUMBER."
2710  GOTO 170
```

```
2720  PRINT "YOU'LL FIND THAT THE CART WILL BE VERY SLOW AND HARD TO HANDLE"
2730  PRINT "WITH MORE THAN 10 BRICKS ON IT. DON'T USE MORE THAN 10 BRICKS."
2740  PRINT "SO, AGAIN --"
2750  GOTO 170
2760  PRINT "THIS PROGRAM IS THE SECOND IN A SERIES.  SINCE THE CONCEPTS"
2770  PRINT "DEVELOPED ARE SEQUENTIAL YOU SHOULD BEGIN BY VIEWING THE FILM"
2780  PRINT "LOOP 'FORCE & MOTION I', THEN RUN FORCEA."
2790  GOTO 2880
2800  IF L#0 THEN 2860
2810  LET L=L+1
2820  PRINT "YOU SHOULD KNOW THE CORRECT ANSWER TO THIS QUESTION IF YOU'VE"
2830  PRINT "BEEN THROUGH 'FORCEA'. I'LL GIVE YOU ONE MORE CHANCE TO"
2840  PRINT "TYPE IT PROPERLY."
2850  GOTO 100
2860  PRINT "RUN 'FORCEA' BEFORE CONTINUING."
2870  GOTO 2880
2880  PRINT "TO SIGN OFF THE TERMINAL TYPE 'BYE' AND PRESS THE RETURN KEY"
2890  END
```

```
WHAT FILE IS TO BE LISTED?
?lunf2
 STARTING RECORD NUMBER?
?1
 1

AS YOU OBSERVED IN THE FILM, WE CAN VARY THE FORCE WE APPLY
 2
BY USING DIFFERENT NUMBERS OF RUBBER LOOPS STRETCHED A CON-
 3
STANT LENGTH; I SUGGEST 60 CM FOR ALL LOOPS IN THIS EXPERIMENT
 4
YOU SPECIFY THE FORCE YOU'LL APPLY IN EACH TRIAL AND
 5
MAKE THE SIMULATED RUN.   THEN I'LL DETERMINE ACCELERATION
 6
FROM THE TICKER TAPE AND PLOT A GRAPH OF ACCELERATION V.
 7
FORCE WHEN WE HAVE ENOUGH DATA.
 8

RIGHT! IN FACT, THERE APPEARS TO BE A LINEAR RELATIONSHIP
 9
BETWEEN FORCE AND ACCELERATION IF WE OVERLOOK THE  IRREGULARITIES
 10
PROBABLY CAUSED BY EXPERIMENTAL ERROR.
 11

NOTE THAT THE GRAPH DOES NOT PASS THROUGH THE ORIGIN.
 12
APPARENTLY THE CART DOES NOT ACCELERATE WHEN WE APPLY A
 13
SMALL POSITIVE FORCE. WHAT COULD CAUSE THIS?
 14

COULD IT BE FRICTION?
 15

FINE! THE FORCE OF FRICTION IS REPRESENTED BY THE INTERCEPT
 16
OF THE GRAP  WITH THE FORCE AXIS.
 17

HAD WE USED A CART WITH GREATER FRICTION THAN IN OUR EXPERIMENT
 18
WOULD THIS INTERCEPT BE TO THE RIGHT OR LEFT OF ITS
 19
PRESENT LOCATION?  (TYPE 'RIGHT' OR 'LEFT')
```

CORRECT! NEXT, I'M GOING TO TAKE THE DATA WE COLLECTED AND PLOT THE RESULTANT FORCE ACTING ON THE CART, INSTEAD OF THE FORCE YOU APPLIED IN EACH RUN. (THE RESULTANT OR NET FORCE IS THE FORCE YOU APPLIED MINUS THE FORCE OF FRICTION.)

AS WE OBSERVED IN THE LAST EXPERIMENT, MASS HAS AN INVERSE RELATIONSHIP TO ACCELERATION WHEN A CONSTANT FORCE IS APPLIED. IN THE NEXT EXPERIMENT WE'LL CONDUCT A QUANTITATIVE STUDY OF THIS RELATIONSHIP.

TO SUMMARIZE, WE CAN SEE FROM OUT DATA THAT ACCELERATION IS DIRECTLY PROPORTIONAL TO THE NET FORCE WHEN THE MASS REMAINS CONSTANT. THE EQUATION FOR THE RELATIONSHIP IS: A=KF. I SHOULD EMPHASIZE THAT F REPRESENTS THE NET OR RESULTANT FORCE; IT IS THE VECTOR SUM OF ALL FORCES ACTING ON THE OBJECT. NOW, TRY THIS PROBLEM:

CORRECT!

YOU HAVE NOW COMPLETED THIS SIMULATED EXPERIMENT. PERHAPS YOU WILL BE ABLE TO PURSUE THE INVESTIGATION FURTHER AT HOME OR IN YOUR LAB.

AFTER YOU'VE SIGNED OFF THE TERMINAL, ROLL OUT SEVERAL INCHES OF PAPER. ON IT LIST THE SOURCES OF EXPERIMENTAL ERROR AS YOU ENVISION THEM AND STATE THE MAJOR CONCLUSIONS YOU CAN DRAW FROM THE EXPERIMENT. INCLUDE THIS PAPER IN YOUR PHYSICS NOTEBOOK.

```
 43
AS SOON AS YOU HAVE THE OPPORTUNITY VIEW THE NEXT FILM
 44
LOOP 'FORCE & MOTION III', THEN RUN 'FORCEC'.
 45

WRONG. THE GRAPH CAN BE REPRESENTED BY A STRAIGHT LINE
 46
PASSING THROUGH THE ORIGIN. FROM YOUR WORK IN ALGEBRA
 47
YOU KNOW THE EQUATION FOR A STRAIGHT LINE: Y=MX+B. (M
 48
IS THE SLOPE AND B THE X-INTERCEPT.) IN THIS CASE, WE'RE
 49
USING 'A' TO REPRESENT ACCELERATION ON THE VERTICAL AXIS
 50
AND 'F' FOR THE FORCE ON THE HORIZONTAL AXIS.  THE FORCE
 51
INTERCEPT IS 0. TRY THE QUESTION AGAIN.
 52


 52    RECORDS IN FILE lunf2
```

```
LIS
FORCEC

10  FILES LUNF3
20  DIM A$[62],N[13,10],O[13,10]
30  MAT N=ZER
40  MAT O=ZER
50  PRINT "HELLO AGAIN. IN THIS THIRD PROGRAM OF THE SERIES WE WILL STUDY HOW A
60  PRINT "CONSTANT FORCE ACCELERATES DIFFERENT MASSES. HAVE YOU COMPLETED 'FORCEB'"
70  PRINT "AND THEN VIEWED FILM LOOP 'FORCE & MOTION III'?"
80  INPUT A$
90  IF A$="YES" THEN 110
100  IF A$#"yes" THEN 2710
110  PRINT "IN THE FIRST EXPERIMENT OF THIS SERIES WE OBSERVED THAT CONSTANT"
120  PRINT "FORCES CAUSE A BODY TO UNDERGO A CONSTANT ACCELERATION.  IN THE "
130  PRINT "LAST EXPERIMENT WE HELD THE MASS CONSTANT AND OBSERVED WHAT KIND OF
140  PRINT " RELATIONSHIP BETWEEN ACCELERATION AND FORCE?"
150  LET L=0
160  INPUT A$
170  IF A$="DIRECT" THEN 210
180  IF A$="direct" THEN 210
190  IF A$="LINEAR" THEN 210
200  IF A$#"linear" THEN 2750
210  READ #1,1
220  FOR I=1 TO 5
230  READ #1;A$
240  PRINT A$
250  NEXT I
260  PRINT "TYPE BELOW THE AMOUNT OF STRETCH IN CM YOU WILL APPLY DURING THE"
270  PRINT "RUNS THROUGHOUT THIS EXPERIMENT."
280  INPUT B
290  IF B<50 THEN 2630
300  IF B>100 THEN 2670
310  READ #1,6
320  FOR I=1 TO 9
330  READ #1;A$
340  PRINT A$
350  NEXT I
360  FOR L=1 TO 12
370  PRINT "HOW MANY BRICKS ARE YOU USING FOR A LOAD IN THIS RUN?"
380  INPUT C
390  IF C<1 THEN 2550
400  IF C>10 THEN 2600
410  LET M=(C+1)*5
420  LET A=INT(40*B/M+.5)/10
430  IF A>24 THEN 450
440  LET N[A/2+1,C]=1
450  IF 50/A>12 THEN 470
460  LET O[50/A+1,C]=1
470  PRINT "FOR YOUR TOTAL MASS OF";C+1;" BRICKS, THE ACCELERATION"
480  PRINT "WAS:";A;" CM/SEC/SEC.     [1/A=";INT(1000/A)/1000;"]"
490  IF L<5 THEN 570
500  PRINT "IF YOU'D LIKE TO MAKE ANOTHER RUN TYPE 'RUN'; IF YOU'D LIKE ME TO"
```

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```
510  PRINT "GRAPH A VERSUS M TYPE 'PLOT'."
520  INPUT A$
530  IF A$="PLOT" THEN 580
540  IF A$="plot" THEN 580
550  IF A$="RUN" THEN 570
560  IF A$="run" THEN 1520
570  NEXT L
580  PRINT
590  GOSUB 2030
600  PRINT "STUDY THE GRAPH CAREFULLY. CAN YOU OBSERVE ANY REGULARITIES?"
610  INPUT A$
620  IF A$="YES" THEN 640
630  IF A$="yes" THEN 1540
640  PRINT "WHAT KIND OF RELATIONSHIP EXOSTS BETWEEN ACCELERATION AND MASS
     (DIRECT"
650  PRINT "OR INVERSE)?"
660  INPUT A$
670  IF A$="INVERSE" THEN 690
680  IF A$="inverse" THEN 2450
690  READ #1,15
700  FOR I=1 TO 10
710  READ #1;A$
720  PRINT A$
730  NEXT I
740  MAT N=0
750  LET L=1
760  GOSUB 2030
770  PRINT "AHA!   VERY INTERESTING."
780  PRINT "THIS GRAPH DOES MAKE THE RELATIONSHIP MORE OBVIOUS. DO YOU SEE W
790  PRINT "I MEAN?"
800  INPUT A$
810  LET L=0
820  PRINT "THE LINEAR GRAPH INDICATES A DIRECT RELATIONSHIP BETWEEN THE TWO"
830  PRINT "VARIABLES WE'VE PLOTTED. "
840  PRINT "WRITE AN EQUATION TO FIT THIS GRAPH. DO NOT BOTHER TO CALCULATE T
850  PRINT "SLOPE; INSTEAD REPRESENT THE SLOPE WITH THE CONSTANT 'K'."
860  PRINT "BEGIN THE EQUATION:  1/A=  ..."
870  INPUT A$
880  IF A$="1/A=KM" THEN 1040
890  IF A$="1/a=km" THEN 1040
900  IF A$="1/A=K*M" THEN 1040
910  IF A$="1/a=k*m" THEN 1040
920  IF A$="1/A=KXM" THEN 1040
930  IF A$="1/A=K×M" THEN 1040
940  IF A$="1/a=kXm" THEN 1040
950  IF A$="1/a=k×m" THEN 1040
960  IF A$="1/A=MK" THEN 1040
970  IF A$="1/a=mk" THEN 1040
980  IF A$="1/A=MXK" THEN 1040
990  IF A$="1/A=M/K" THEN 1040
1000  IF A$="1/a=mXk" THEN 1040
1010  IF A$="1/a=m×k" THEN 1040
1020  IF A$="1/a=m*k" THEN 1040
1030  IF A$="1/A=M*K" THEN 2310
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```
1040  LET L=0
1050  READ #1,25
1060  FOR I=1 TO 8
1070  READ #1:A$
1080  PRINT A$
1090  NEXT I
1100  LET E=4*B/75
1110  PRINT "MASS OF ROCK AND CART (TO THE NEAREST 10TH BRICK)?"
1120  LET L=0
1130  INPUT D
1140  LET F=INT(D+.5)
1150  IF F#INT(E+.5) THEN 1570
1160  PRINT "OK: THE MASS OF ROCK AND CART IS:";E;" BRICKS."
1170  PRINT "WHAT IS THE MASS OF THE ROCK ALONE?"
1180  LET L=0
1190  INPUT F
1200  IF F=D-1 THEN 1220
1210  IF INT(F+.5)#INT(E-.5) THEN 1680
1220  READ #1,33
1230  FOR I=1 TO 6
1240  READ #1:A$
1250  PRINT A$
1260  NEXT I
1270  LET L=0
1280  PRINT "NOW TRY THIS PROBLEM:"
1290  PRINT "A CAR HAS A MAXIMUM ACCELERATION OF 8 M/SEC/SEC. IF THE CAR TOWS"
1300  PRINT "ANOTHER CAR OF IDENTICAL MASS AND DESIGN, WHAT WILL BE THE MAXIMUM"
1310  PRINT "ACCEL. IN M/SEC/SEC?"
1320  INPUT D
1330  IF D#4 THEN 1800
1340  PRINT "GOOD! NOW HERE'S ANOTHER PROBLEM:"
1350  PRINT "MASS A ACCELERATES AT 80 FT/SEC/SEC AND MASS B ACCELERATES AT"
1360  PRINT "20 FT/SEC/SEC WHEN IDENTICAL FORCES ARE APPLIED."
1370  PRINT "WHAT IS THE RATIO: MASS A/MASS B?"
1380  INPUT A$
1390  IF A$=".25" THEN 1420
1400  IF A$="1/4" THEN 1420
1410  IF A$#"1:4" THEN 1910
1420  PRINT "CORRECT!"
1430  PRINT "YOU HAVE NOW COMPLETED THIS SIMULATED EXPERIMENT. PERHAPS YOU WILL
      BE"
1440  PRINT "ABLE TO PURSUE THE INVESTIGATION FURTHER AT HOME OR IN YOUR LAB. "
1450  PRINT "AFTER YOU'VE SIGNED OFF THE TERMINAL ROLL OUT SEVERAL EXTRA INCHES
      OF"
1460  PRINT "PAPER. ON IT LIST THE SOURCES OF EXPERIMENTAL ERROR AS YOU ENVISION
1470  PRINT "THEM AND STATE THE MAJOR CONCLUSIONS YOU CAN DRAW FROM THE
      EXPERIMENT."
1480  PRINT "INCLUDE THIS PAPER IN YOUR PHYSICS NOTEBOOK."
1490  PRINT "AS SOON AS YOU HAVE THE OPPORTUNITY VIEW THE NEXT FILM LOOP 'FORCE
      &"
1500  PRINT "MOTION IV' AND RUN 'FORCED'."
1510  GOTO 2330
1520  PRINT "YOU DIDN'T TYPE 'PLOT' OR 'RUN'. AGAIN, WHICH SHOULD WE DO?"
1530  GOTO 520
1540  PRINT "LOOK AT THE GRAPH AGAIN. THE PLOTTED POINTS SHOW THAT AS MASS
      INCREASES"
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```
1550  PRINT "ACCELERATION DECREASES: THE PLOT FORMS A SMOOTH CURVE."
1560  GOTO 640
1570  IF L>1 THEN 1640
1580  LET L=L+1
1590  PRINT "SORRY, YOU'RE WRONG. AN EASY WAY TO DETERMINE THE TOTAL MASS I
      GO"
1600  PRINT "BACK TO THE FIRST GRAPH OF A V. M AND READ THE MASS DIRECTLY F
1610  PRINT "THE GRAPH FOR AN ACCELERATION OF 15.0CM/SEC/SEC. ANSWER THE
      QUESTION"
1620  PRINT "AGAIN."
1630  GOTO 1130
1640  PRINT "WRONG AGAIN. THE ANSWER IS :";E;" BRICKS. IF YOU DON'T UNDERST
1650  PRINT "DISCUSS THIS WITH YOUR TEACHER AS SOON AS POSSIBLE. NOW WHAT I
      MASS"
1660  PRINT "OF THE ROCK ALONE?"
1670  GOTO 1190
1680  IF L>1 THEN 1760
1690  LET L=L+1
1700  READ #1,53
1710  FOR I=1 TO 5
1720  READ #1;A$
1730  PRINT A$
1740  NEXT I
1750  GOTO 1190
1760  PRINT "NO. THE MASS OF THE RICK IS:"E-1;" BRICKS. YOU NEED ASSISTANCE
1770  PRINT "INTERPRETING THE GRAPH."
1780  PRINT "CONSULT WITH YOUR TEACHER BEFORE CONTINUING THIS PROGRAM."
1790  GOTO 2330
1800  IF L>1 THEN 1850
1810  LET L=L+1
1820  PRINT "INCORRECT. REMEMBER, ACCEL. IS INVERSELY PROPORTIONAL TO MASS.
      TWICE"
1830  PRINT "THE MASS IS PRESENT IN THE 2ND ACCELERATION. ANSWER THE QUESTI
      AGAIN."
1840  GOTO 1320
1850  READ #1,58
1860  FOR I=1 TO 4
1870  READ #1;A$
1880  PRINT A$
1890  NEXT I
1900  GOTO 1350
1910  IF L>2 THEN 2000
1920  LET L=L+1
1930  READ #1,62
1940  FOR I=1 TO 2
1950  READ #1;A$
1960  PRINT A$
1970  NEXT I
1980  PRINT "TRY THE QUESTION AGAIN."
1990  GOTO 1370
2000  PRINT "THE ACCELERATION RATIO IS THE INVERSE OF THE MASS RATIO OF 1/4
2010  PRINT "YOU NEED FURTHER ASSISTANCE IN UNDERSTANDING THIS CONCEPT."
2020  GOTO 1780
2030  FOR Y=12 TO 1 STEP -1
2040  READ A$
2050  PRINT A$;
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```
2060  IF Y/2=INT(Y/2) THEN 2170
2070  IF L=1 THEN 2100
2080  PRINT TAB(7);2*Y;
2090  GOTO 2170
2100  IF 2*Y=8 THEN 2140
2110  IF 2*Y=4 THEN 2160
2120  PRINT TAB(6);"."2*Y;
2130  GOTO 2170
2140  PRINT TAB(6);". 08";
2150  GOTO 2170
2160  PRINT TAB(6);". 04";
2170  FOR X=1 TO 10
2180  IF N[Y+1,X]=1 THEN 2220
2190  NEXT X
2200  PRINT TAB(13);"+"
2210  GOTO 2230
2220  PRINT TAB(13);"+";TAB(13+(X+1)*4);"X"
2230  NEXT Y
2240  PRINT "         0    + + + +-+ + + + + + + + + + + + + + + + + + + +"
2250  PRINT TAB(13);"0  1   2   3   4   5   6   7   8   9   10  11"
2260  PRINT TAB(27);"TOTAL MASS (BRICKS)"
2270  PRINT
2280  DATA "A","C","C","E","L","E(CM/SEC/SEC)","R","A","T","I","O","N"
2290  DATA "","","","","","","  1/A ","","","","","",""
2300  RETURN
2310  IF L>1 THEN 2390
2320  LET L=L+1
2330  READ #1,43
2340  FOR I=1 TO 6
2350  READ #1;A$
2360  PRINT A$
2370  NEXT I
2380  GOTO 840
2390  READ #1,49
2400  FOR I=1 TO 4
2410  READ #1;A$
2420  PRINT A$
2430  NEXT I
2440  GOTO 840
2450  IF A$="DIRECT" THEN 2490
2460  IF A$="direct" THEN 2490
2470  PRINT "YOUR ANSWER MUST BE 'DIRECT' OR 'INVERSE'. SO, AGAIN --"
2480  GOTO 640
2490  READ #1,39
2500  FOR I=1 TO 4
2510  READ #1;A$
2520  PRINT A$
2530  NEXT I
2540  GOTO 640
2550  PRINT "YOU WILL FIND THAT IF YOUR CART HAS NO BRICKS ON IT AND YOU APPLY A"
2560  PRINT "FORCE OF";R;" ON THE CART WILL TAKE OFF SO FAST YOU WON'T BE ABLE
TO"
2570  PRINT "APPLY A CONSTANT FORCE. I SUGGEST AT LEAST 1 BRICK FOR A LOAD."
2580  PRINT "SO, AGAIN --"
2590  GOTO 370
2600  PRINT "WITH MORE THAN 10 BRICKS THE CART IS VERY SLOW AND HARD TO HANDLE."
```

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```
2610  PRINT "DON'T USE MORE THAN 10 BRICKS. SO, AGAIN --"
2620  GOTO 490
2630  PRINT "THE UNSTRETCHED RUBBER LOOP IS ALMOST 50 CM LONG WHEN WE STRETCH
      THIS"
2640  PRINT "LOOP LESS THAN 50CM WE'RE NOT APPLYING A SIGNIFICANT FORCE TO TH
2650  PRINT "CART. SO, AGAIN--"
2660  GOTO 260
2670  PRINT "WE'RE STRETCHING THE LOOP WITH A METER STICK WHICH IS 100CM LONG
      YOU"
2680  PRINT "CAN'T APPLY A CONSTANT FORCE ACCURATELY IF THE STRETCH EXCEEDS"
2690  PRINT "100CM. SO, AGAIN --"
2700  GOTO 260
2710  PRINT " THIS PROGRAM IS THIRD IN A SERIES. SINCE THE CONCEPTS DEVELOPE
2720  PRINT "ARE SEQUENTIAL YOU SHOULD BEGIN BY VIEWING THE FILM LOOP 'FORCE
2730  PRINT "MOTION I' AND THEN RUN 'FORCEA'."
2740  GOTO 2830
2750  IF L#0 THEN 2810
2760  LET L=L+1
2770  PRINT "YOU SHOULD KNOW THE CORRECT ANSWER TO THIS QUESTION IF YOU'VE
2780  PRINT "THROUGH FORCEB. I'LL GIVE YOU ONE MORE CHANCE TO TYPE IT"
2790  PRINT "PROPERLY."
2800  GOTO 160
2810  PRINT "RUN THE PROGRAM 'FORCEB' BEFORE CONTINUING."
2820  GOTO 2830
2830  PRINT "TO SIGN OFF THE TERMINAL TYPE 'BYE' AND PRESS THE RETURN KEY."
2840  END
```

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lunf3

RIGHT. NOW TO STUDY HOW ACCELERATION VARIES WHEN THE OBJECT'S MASS IS CHANGED WE'LL TRY TO HOLD ALL OTHER VARIABLES CONSTANT. WE'LL APPLY THE SAME FORCE TO THE CART IN ALL RUNS BY KEEPING ONE LOOP OF RUBBER STRETCHED A CONSTANT LENGTH. (WE CAN STRETCH OUR LOOP BETWEEN 50 AND 100CM.)

WE CAN VARY THE CART'S MASS BY USING DIFFERENT NUMBERS OF IDENTICAL BRICKS FOR A LOAD. THE MASS OF THE EMPTY CART WE'LL USE HAS BEEN ADJUSTED TO EQUAL THE MASS OF ONE BRICK.

YOU SPECIFY THE NUMBER OF BRICKS YOU'LL USE FOR A LOAD IN EACH TRIAL AND MAKE THE SIMULATED RUN. THEN I'LL DETERMINE ACCELERATION FROM THE TICKER TAPE AND PLOT A GRAPH OF ACCELERATION V. MASS. REMEMBER, THE MASS YOU'RE ACCELERATING IS ONE BRICK LARGER THAN THE LOAD YOU SPECIFY SINCE THE CART HAS A MASS OF 1 BRICK.

RIGHT! AS THE CART'S MASS GETS LARGER THE ACCELERATION GETS SMALLER UNDER THE INFLUENCE OF A CONSTANT FORCE.

OUR NEXT TASK IS TO FIND AN ALGEBRAIC EXPRESSION FOR THE RELATIONSHIP BETWEEN ACCELERATION AND MASS. A STUDY OF OUR GRAPH SUGGESTS THAT IT MIGHT BE A 1ST POWER INVERSE RELATIONSHIP. THAT IS: ACCEL. IS DIRECTLY PROPORTIONAL TO 1/MASS. OR MASS IS DIRECTLY PROPORTIONAL TO 1/ACCELERATION. TO CHECK OUT THIS PREDICTION I WILL PLOT A NEW GRAPH OF 1/A VERSUS MASS FOR EACH OF OUR RIALS USING THE DATA WE COLLECTED.

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```
HERE'S THE NEW GRAPH:

 25

RIGHT! THERE IS A DIRECT RELATIONSHIP BETWEEN 1/A AND MASS;
 26
K COULD OF COURSE BE REPLACED BY THE NUMERICAL VALUE FOR THE
 27
SLOPE OF THE LINE.
 28

HERE IS A PROBLEM FOR YOU TO TRY USING YOUR GRAPH AND THE
 29
SIMULATED APPARATUS: A ROCK OF UNKNOWN MASS IS PLACED ON OUR
 30
UNLOADED CART. YOU MAKE A RUN WITH IT APPLYING THE SAME FORCE
 31
AS YOU DID IN THE OTHER RUNS. MY ANALYSIS OF THE TAPE INDI-
 32
CATES AN ACCELERATION OF 15.0CM/SEC/SEC. WHAT IS THE TOTAL
 33

GOOD! THIS IS ONE METHOD WHICH CAN BE USED TO DETERMINE THE
 34
INERTIAL MASS OF AN OBJECT.
 35

TO SUMMARIZE, WE CAN SEE FROM THE GRAPHS OF OUR DATA THAT
 36
THE ACCELERATION OF AN OBJECT IS INVERSELY PROPORTIONAL TO
 37
ITS INERTIAL MASS WHEN A CONSTANT FORCE IS APPLIED, AND
 38
THE EQUATION YOU WROTE FOR THE RELATIONSHIP IS: 1/A=KM.
 39

WRONG. WHEN 2 VARIABLES ARE DIRECTLY RELATED, ONE INCREASES
 40
AS THE OTHER INCREASES.  LOOK AT YOUR GRAPH AGAIN. IT SHOWS
 41
THAT THE ACCELERATION BECAME SMALLER AS THE MASS INCREASED.
 42
THIS MEANS THAT THE VARIABLES ARE INVERSELY RELATED. SO
 43

WRONG. THE GRAPH CAN BE REPRESENTED BY A STRAIGHT LINE PASS-
 44
ING THROUGH THE ORIGIN. FROM YOUR WORK IN ALGEBRA YOU KNOW
 45
THE EQUATION FOR A STRAIGHT LINE. (Y=MX+B WHERE M IS THE
 46
SLOPE AND B THE X-INTERCEPT.) IN THIS CASE WE'RE PLOTTING 1/A
 47
ON THE VERTICAL AXIS AND MASS ON THE HORIZONTAL AXIS. THE
```

```
 48
MASS INTERCEPT IS 0. TRY THE QUESTION AGAIN.
 49

NO. THE EQUATION SHOULD BE EXPRESSED AS: 1/A=KM. IF YOU
 50
DON'T UNDERSTAND WHY DISCUSS THIS WITH YOU TEACHER AS
 51
SOON AS POSSIBLE. NOW HERE'S THE QUESTION ONCE MORE. TYPE
 52
IN THE EQUATION I'VE STATED.
 53

NO. YOU'RE WRONG. REMEMBER THAT WE ACCELERATED THE ROCK AND
 54
THE CART AND WE HAVE PLOTTED THE TOTAL MASS. TO FIND THE
 55
MASS OF THE ROCK WE MUST SUBTRACT THE CART'S MASS (1 BRICK)
 56
FROM THE TOTAL MASS DETERMINED IN THE LAST QUESTION.
 57

TRY THE QUESTION AGAIN.

 58

WRONG. WITH TWICE THE MASS THE CONSTANT FORCE CAUSES 1/2
 59
THE ORIGINAL ACCELERATION OR 4M/SEC/SEC. IF YOU DON'T
 60
UNDERSTAND DISCUSS THIS WITH YOUR TEACHER AS SOON AS
 61
POSSIBLE. NOW HERE'S ANOTHER PROBLEM.
 62

NO. THE PROBLEM ASKS FOR THE RATIO OF MASS A/MASS B. THIS IS
 63
EQUIVALENT TO ACCEL.B/ACCEL.A DUE TO THE INVERSE RELATIONSHIP.
 64
```

```
list
FORCED

10   FILES LUNF4
20   DIM A$[65]
30   READ #1,1
40   FOR I=1 TO 4
50   READ #1;A$
60   PRINT A$
70   NEXT I
80   INPUT A$
90   IF A$="yes" THEN 110
100   IF A$#"YES" THEN 2870
110   READ #1,5
120   FOR I=1 TO 6
130   READ #1;A$
140   PRINT A$
150   NEXT I
160   LET L=0
170   INPUT A$
180   IF A$="inverse" THEN 200
190   IF A$#"INVERSE" THEN 2930
200   READ #1,11
210   FOR I=1 TO 12
220   READ #1;A$
230   PRINT A$
240   NEXT I
250   PRINT "I'VE JUST TYPED A LOT OF INFORMATION HERE. READ IT CAREFULLY AND TYPE"
260   PRINT "'GO' WHEN YOU UANT ME TO CONTINUE."
```

```
270  INPUT A$
280  IF A$="GO" THEN 330
290  IF A$="go" THEN 330
300  PRINT "YOU DIDN'T TYPE 'GO'. I CAN'T CONTINUE UNTIL YOU DO."
310  PRINT "TYPE 'GO' AND WE'LL CONTINUE."
320  GOTO 270
330  PRINT "IN THE EQUATION K IS A CONSTANT OF PROPORTIONALITY AND ITS"
340  PRINT "NUMERICAL VALUE DEPENDS UPON THE UNITS USED TO MEASURE FORCE,"
350  READ #1,23
360  FOR I=1 TO 18
370  READ #1;A$
380  PRINT A$
390  NEXT I
400  LET L=0
410  PRINT "WHAT IS THE NET FORCE (IN NEWTONS) ACTING ON THE SPACESHIP?"
420  INPUT A$
430  IF A$="1200" THEN 450
440  IF A$#"1,200" THEN 1660
450  PRINT "CORRECT! NOW HERE'S A SLIGHT VARIATION OF THE SAME PROBLEM:"
460  PRINT "AN 80KG ASTRONAUT IN EQUILIBRIUM OUTSIDE HIS SPACESHIP RECEIVES A"
470  PRINT "40N FORCE FROM A PROPULSION JET ATTACHED TO HIM."
480  LET L=0
490  PRINT "WHAT ACCEL. (IN M/SEC/SEC) DOES HE EXPERIENCE?"
500  INPUT A$
510  IF A$=".5" THEN 530
520  IF A$#"1/2" THEN 1620
530  READ #1,41
540  FOR I=1 TO 2
550  READ #1;A$
560  PRINT A$
570  NEXT I
580  PRINT "TRY THIS PROBLEM AGAIN WHICH INVOLVES NEGATIVE ACCELERATION: A 2000"
590  READ #1,43
600  FOR I=1 TO 4
610  READ #1;A$
620  PRINT A$
630  NEXT I
640  LET L=0
650  INPUT A$
660  IF A$="4000" THEN 700
670  IF A$="4,000" THEN 700
680  IF A$="-4000" THEN 700
690  IF A$#"-4,000" THEN 1880
700  LET L=0
710  READ #1,47
720  FOR I=1 TO 6
730  READ #1;A$
740  PRINT A$
750  NEXT I
760  PRINT "WHAT IS THE FRICTIONAL FORCE ACTING ON THE STOVE IN N?"
770  INPUT A$
780  IF A$="250" THEN 800
790  IF A$#"-250" THEN 2000
800  LET L=0
810  READ #1,53
```

```
820  FOR I=1 TO 4
830  READ #1;A$
840  PRINT A$
850  NEXT I
860  INPUT D
870  IF D#1.5 THEN 2100
880  READ #1,57
890  FOR I=1 TO 4
900  READ #1;A$
910  PRINT A$
920  NEXT I
930  PRINT TAB(9);"10+"
940  PRINT "V";TAB(11);"+"
950  PRINT "E";TAB(10);"8+";TAB(27);"X    X    X"
960  PRINT "L";TAB(11);"+";TAB(23);"X"
970  PRINT "O";TAB(10);"6+          X";TAB(37);"X"
980  PRINT "C (M/SEC)   +    X"
990  PRINT "I";TAB(10);"4X";TAB(39);"X"
1000  PRINT "T";TAB(11);"+";TAB(41);"X"
1010  PRINT "Y";TAB(10);"2+";TAB(43);"X"
1020  PRINT TAB(11);"+";TAB(45);"X"
1030  PRINT TAB(10);"0+ + + + + + + + + + + + + + + + + X + +"
1040  PRINT TAB(11);"0   2   4   6   8   10  12  14  16  18  20"
1050  PRINT TAB(26);"TIME (SEC)"
1060  LET L=0
1070  READ #1,61
1080  FOR I=1 TO 2
1090  READ #1;A$
1100  PRINT A$
1110  NEXT I
1120  PRINT "1. THE NET FORCE ACTING ON THE OBJECT WAS 0 AT: (A) 0 SEC; (B)"
1130  PRINT "4SEC; (C) 10SEC; (D) 13SEC; (E) 16SEC; (F) NONE OF THE ABOVE"
1140  INPUT A$
1150  IF A$="c" THEN 1170
1160  IF A$#"C" THEN 2260
1170  READ #1,64
1180  FOR I=1 TO 4
1190  READ #1;A$
1200  PRINT A$
1210  NEXT I
1220  INPUT A$
1230  IF A$="d" THEN 1250
1240  IF A$#"D" THEN 2360
1250  PRINT "GOOD!"
1260  PRINT "3. THE NET FORCE WAS CONSTANT BETWEEN:(A) 6-9SEC; (B) 9-13SEC;"
1270  PRINT "(C) 13-15SEC; (D) 15-18SEC; (E) NONE OF THE ABOVE"
1280  INPUT A$
1290  IF A$="d" THEN 1310
1300  IF A$#"D" THEN 2450
1310  PRINT "CORRECT!"
1320  LET L=0
1330  PRINT "4. WHAT WAS THE ACCEL. OF THE OBJECT (IN M/SEC/SEC) AT 6 SEC?"
1340  INPUT A$
1350  IF A$=".5" THEN 1370
1360  IF A$#"1/2" THEN 2540
```

```
1370  PRINT "FINE!"
1380  PRINT "5. DETERMINE THE NET FORCE (IN N) AT 6 SEC. (OBJECT HAS MASS OF 10KG)"
1390  INPUT D
1400  IF D#5 THEN 2630
1410  PRINT "VERY NICE."
1420  PRINT "YOU'LL NOTICE ON THE GRAPH THAT THIS CONSTANT FORCE OF 5N WAS APPLIED"
1430  PRINT "FROM 0SEC THROUGH 8 SEC. NOW, THE FINAL PROBLEM:"
1440  PRINT "6. DETERMINE THE FORCE (IN N) ACTING AT 13 SEC."
1450  LET L=0
1460  INPUT D
1470  IF ABS(D)#20 THEN 2700
1480  READ #1,68
1490  FOR I=1 TO 17
1500  READ #1;A$
1510  PRINT A$
1520  NEXT I
1530  LET L=0
1540  PRINT "BEGIN THE EQUATION: F= ... AND DO NOT INCLUDE A MULTIPLICATION SIGN."
1550  INPUT A$
1560  IF A$="F=MA" THEN 1640
1570  IF A$="f=ma" THEN 1640
1580  IF A$="F=KMA" THEN 1640
1590  IF A$="f=kma" THEN 1640
1600  IF A$="A=F/M" THEN 1640
1610  IF A$="a=f/m" THEN 1640
1620  IF A$="a=kf/m" THEN 1640
1630  IF A$#"A=KF/M" THEN 2780
1640  PRINT "AUF WIEDERSEHEN"
1650  GOTO 3030
1660  IF L>1 THEN 1740
1670  LET L=L+1
1680  READ #1,91
1690  FOR I=1 TO 3
1700  READ #1;A$
1710  PRINT A$
1720  NEXT I
1730  GOTO 410
1740  READ #1,94
1750  FOR I=1 TO 3
1760  READ #1;A$
1770  PRINT A$
1780  NEXT I
1790  GOTO 460
1800  IF L>1 THEN 1840
1810  LET L=L+1
1820  PRINT "NO. SINCE F=MA, A=F/M. TRY THE PROBLEM AGAIN:"
1830  GOTO 490
1840  PRINT "40N/80KG=1/2M/SEC/SEC."
1850  PRINT "YOU NEED FURTHER ASSISTANCE IN UNDERSTANDING THIS CONCEPT. CONSULT"
1860  PRINT "WITH YOUR TEACHER BEFORE CONTINUING THIS PROGRAM."
1870  GOTO 3030
1880  LET L=L+1
1890  IF L=3 THEN 1940
1900  IF L>3 THEN 1850
1910  PRINT "WRONG ANSWER. FIRST FIND THE CAR'S ACCEL. (IT LOSES 30M/SEC IN 15 SEC."
1920  PRINT "THEN: F=MA. CHECK THE PROBLEM AND TYPE IN YOUR NEW ANSWER."
```

```
1930  GOTO 650
1940  READ #1,97
1950  FOR I=1 TO 4
1960  READ #1;A$
1970  PRINT A$
1980  NEXT I
1990  GOTO 650
2000  IF L>1 THEN 2080
2010  LET L=L+1
2020  READ #1,101
2030  FOR I=1 TO 5
2040  READ #1;A$
2050  PRINT A$
2060  NEXT I
2070  GOTO 760
2080  PRINT "NO. THE FRICTIONAL FORCE IS 250N."
2090  GOTO 1850
2100  LET L=L+1
2110  IF L=3 THEN 2190
2120  IF L>3 THEN 1850
2130  READ #1,106
2140  FOR I=1 TO 4
2150  READ #1;A$
2160  PRINT A$
2170  NEXT I
2180  GOTO 860
2190  PRINT "NO. MASS A=F/A=12/2=6KG; MASS B =12/6=2KG."
2200  READ #1,110
2210  FOR I=1 TO 4
2220  READ #1;A$
2230  PRINT A$
2240  NEXT I
2250  GOTO 860
2260  IF L>1 THEN 2320
2270  LET L=L+1
2280  PRINT "WRONG. SINCE F=MA, THE FORCE = 0 WHERE THE ACCEL. = 0."
2290  PRINT "THE ACCEL. = 0 WHERE THE VELOCITY IS NOT CHANGING.  TRY THE PROBLEM"
2300  PRINT "AGAIN AND TYPE IN THE CORRECT ANSWER"
2310  GOTO 1140
2320  PRINT "NO. THE ACCEL. IS 0 BETWEEN 8 AND 12 SEC. IF YOU DON'T UNDERSTAND"
2330  PRINT "DISCUSS THIS WITH YOUR TEACHER AS SOON AS POSSIBLE. NOW, TYPE IN THE"
2340  PRINT "LETTER OF THE CORRECT RESPONSE."
2350  GOTO 1140
2360  IF L>2 THEN 2430
2370  LET L=L+1
2380  PRINT "WRONG. SINCE F=MA, THE FORCE IS GREATEST WHERE THE ACCEL. IS GREATEST."
2390  PRINT "REMEMBER THAT THE ACCEL. AT ANY POINT IS THE SLOPE OF THE V VERSUS T"
2400  PRINT "GRAPH. FIND THE PLACE WHERE THE VELOCITY IS CHANGING AT THE GREATEST"
2410  PRINT "RATE. NOW TYPE IN THE CORRECT ANSWER."
2420  GOTO 1220
2430  PRINT "NO; THE FORCE IS GREATEST AT 13 SEC."
2440  GOTO 1850
2450  IF L>1 THEN 2520
2460  LET L=L+1
2470  PRINT "INCORRECT. THE FORCE IS CONSTANT WHERE THE ACCEL. IS CONSTANT."
2480  PRINT "REMEMBER THAT THE ACCEL. AT ANY POINT IS THE SLOPE OF THE V VERSUS T"
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2490  PRINT "GRAPH. FIND THE LISTED TIME INTERVAL IN WHICH VELOCITY CHANGES AT A"
2500  PRINT "CONSTANT RATE, AND TYPE IN THE CORRECT ANSWER."
2510  GOTO 1280
2520  PRINT "NO. THE CORRECT CHOICE WAS 15-18SEC."
2530  PRINT "NO. THE CORRECT CHOICE IS 15-18 SEC."
2540  IF L>1 THEN 2600
2550  LET L=L+1
2560  PRINT "WRONG. ACCEL. AT ANY POINT IS THE SLOPE OF THE V VERSUS T GRAPH."
2570  PRINT "A=CHANGE IN V/CHANGE IN T. CHECK YOUR CALCULATION AND TYPE IN THE"
2580  PRINT "CORRECT ANSWER."
2590  GOTO 1340
2600  PRINT "NO. THE SLOPE IS .5M/SEC/SEC. LOOK AT THE GRAPH AND SEE IF YOU AGREE."
2610  PRINT "THEN TRY THIS QUESTION:"
2620  GOTO 1380
2630  IF L>2 THEN 2680
2640  LET L=L+1
2650  PRINT "WRONG. F=MA. MULTIPLY THE MASS(10KG) BY THE ACCEL. CALCULATED IN THE"
2660  PRINT "LAST PROBLEM. CHECK YOUR CALCULATIONS AND TYPE IN THE CORRECT ANSWER."
2670  GOTO 1390
2680  PRINT "NO. F=MA=10X.5=5N."
2690  GOTO 1850
2700  IF L>1 THEN 2760
2710  LET L=L+1
2720  PRINT "INCORRECT. FIND THE ACCEL. AS YOU DID IN PROBLEM #4 ABOVE"
2730  PRINT "(CHANGE IN V/CHANGE IN T). THEN F=MA. CHECK YOUR CALCULATIONS AGAIN"
2740  PRINT "AND TYPE IN THE CORRECT FORCE."
2750  GOTO 1460
2760  PRINT "NO, THE ANSWER IS: -20N."
2770  GOTO 1850
2780  IF L>0 THEN 2840
2790  LET L=L+1
2800  PRINT "YOU MUST BE KIDDING! I'VE SPENT ALL THIS TIME WITH YOU AND YOU CAN'T"
2810  PRINT " SAY 'F=MA'??"
2820  PRINT "OH, THIS IS AWFUL! TRY TYPING THE EQUATION AGAIN."
2830  GOTO 1550
2840  PRINT "NOW I'LL BELIEVE YOU'RE KIDDING. I'LL TYPE IT FOR YOU:"
2850  PRINT "F=MA"
2860  GOTO 1640
2870  READ #1,85
2880  FOR I=1 TO 3
2890  READ #1;A$
2900  PRINT A$
2910  NEXT I
2920  GOTO 3030
2930  IF L#0 THEN 3010
2940  LET L=L+1
2950  READ #1,88
2960  FOR I=1 TO 3
2970  READ #1;A$
2980  PRINT A$
2990  NEXT I
3000  GOTO 170
3010  PRINT "RUN 'FORCEC' BEFORE CONTINUING."
3020  GOTO 3030
3030  PRINT "TO SIGN OFF THE TERMINAL TYPE 'BYE' AND PRESS THE RETURN KEY."
3040  END
```

```
WHAT FILE IS TO BE LISTED?
?lunf4
 STARTING RECORD NUMBER?
?1
 1
HI! IN THIS FINAL PROGRAM OF THE SERIES WE WILL DISCUSS WHAT
 2
WE'VE LEARNED ABOUT FORCE AND MOTION AND INTRODUCE A SYSTEM
 3
OF UNITS IN COMMON USE. HAVE YOU COMPLETED 'FORCEC' AND THEN
 4
VIEWED FILM LOOP 'FORCE & MOTION IV'?
 5

IN THE FIRST EXPERIMENT WE OBSERVED THAT A CONSTANT FORCE
 6
CAUSES A BODY TO UNDERGO A CONSTANT ACCELERATION. IN THE
 7
2ND EXPERIMENT WE OBSERVED THAT ACCELERATION WAS DIRECTLY
 8
PROPORTIONAL TO THE NET FORCE. IN THE 3RD EXPERIMENT WE
 9
OBSERVED WHAT KIND OF RELATIONSHIP BETWEEN ACCELERATION AND
 10
MASS?
 11

CORRECT! WE MAY WRITE THIS LAST STATEMENT AS:
 12

1) M IS DIRECTLY PROPORTIONAL TO 1/A OR
 13
2) A IS DIRECTLY PROPORTIONAL TO 1/M
 14

FROM THE RESULTS OF EXPERIMENT 2 WE CAN WRITE:
 15
3) A IS DIRECTLY PROPORTIONAL TO F
 16

STATEMENTS (2) & (3) CAN BE COMBINED AND WRITTEN AS:
 17
A IS DIRECTLY PROPORTIONAL TO F/M
 18

AN EQUIVALENT STATEMENT IS:
 19
MA IS DIRECTLY PROPORTIONAL TO F
```

OR: F IS DIRECTLY PROPORTIONAL TO MA

IN EQUATION FORM:

$F=KMA$

MASS, AND ACCELERATION. IT WOULD HAVE A SPECIFIC VALUE IF WE CONTINUED TO MEASURE FORCE IN 'BANDS' AND MASS IN 'BRICKS'. THE UNITS WE USED HAPPENED TO BE CONVENIENT FOR US, BUT THEY ARE NOT IN COMMON USE IN THE WORLD. THE EQUATION, OFTEN REFERRED TO AS NEWTON'S 2ND LAW, IS PERHAPS THE MOST FUNDAMENTAL EQUATION IN CLASSICAL MECHANICS, AND THE UNIT OF FORCE COMMONLY USED IS DEFINED SO THAT K IN THE EQUATION = 1.

IN SCIENTIFIC WORK A VERY COMMON UNIT OF MASS IN USE TODAY IS THE KILOGRAM (KG). THE BASIC UNIT OF FORCE WILL CAUSE A MASS OF 1 KILOGRAM TO ACCELERATE AT 1M/SEC/SEC. THIS UNIT OF FORCE IS CALLED THE NEWTON (N). IN OTHER WORDS A FORCE OF 1N WILL CAUSE A MASS OF 1KG TO ACCELERATE 1M/SEC/SEC. USING THESE UNITS THE EQUATION IS WRITTEN:

$F=MA$

$1N=1KG\ M/SEC/SEC$

TRY THE FOLLOWING PROBLEM USING THE MKS (METER,KILOGRAM, SECOND) SYSTEM OF UNITS. A 600KG SPACESHIP IS PROPELLED BY A ROCKET ENGINE. ITS ACCELERATION IS 2M/SEC/SEC.

RIGHT! IT IS IMPORTANT TO POINT OUT AS I DID IN EXP. 2 THAT F REPRESENTS THE VECTOR SUM OF ALL FORCES ACTING ON THE OBJECT. KG CAR IS TRAVELLING AT A SPEED OF 30M/SEC WHEN THE BRAKES

```
 44
ARE APPLIED. THE CAR STOPS IN 15 SEC. IF WE ASSUME A CON-
 45
STANT ACCELERATION, WHAT WAS THE FORCE (IN N) APPLIED BY THE
 46
BRAKES?
 47

GOOD! THE NEGATIVE BRAKING FORCE PRODUCED A NEGATIVE ACCEL.
 48
IF THE VECTOR SUM OF THE FORCES ON A OBJECT = 0, THEN THE
 49
OBJECT WILL UNDERGO 0 ACCELERATION. IN OTHER WORDS ITS
 50
VELOCITY WILL NOT CHANGE.  HERE'S A PROBLEM ON THE SUBJECT:
 51
TO PUSH MY STOVE ACROSS MY KITCHEN FLOOR AT A CONSTANT
 52
SPEED OF 1M/SEC, I MUST APPLY A FORCE OF 250N.
 53

SURE! NOW TRY THIS PROBLEM: A FORCE OF 12N GIVES MASS A
 54
AN ACCEL. OF 2M/SEC/SEC AND MASS B AN ACCEL. OF 6M/SEC/SEC.
 55
WHAT IS THE ACCEL, (IN M/SEC/SEC) WHEN THE TWO ARE FASTENED
 56
TOGETHER AND THE SAME FORCE IS APPLIED?
 57

GOOD!

 58
THE LAST FEW QUESTIONS DEAL WITH THE GRAPH PRINTED BELOW
 59
WHICH SHOWS THE VELOCITY OF A 10KG  OBJECT ALONG A STRAIGHT
 60
PATH.
 61

IN THE NEXT 3 QUESTIONS TYPE IN THE LETTER OF THE BEST
 62
RESPONSE:
 63

 64

CORRECT!

 65

2. THE NET FORCE ACTING ON THE OBJECT WAS GREATEST AT:
 66
(A) 0 SEC; (B) 4 SEC; (C) 10 SEC; (D) 13 SEC; (E) 16 SEC;
```

```
 67
(F) NONE OF THE ABOVE.
 68

OK! IT'S A GOOD IDEA TO WRITE THIS FORCE AS -20N SINCE
 69
THE FORCE IS OPPOSITE THE DIRECTION IN WHICH THE OBJECT IS
 70
MOVING.
 71

THE IDEAS WE'VE BEEN DISCUSSING IN THESE FOUR PROGRAMS ARE
 72
FUNDAMENTAL IN CLASSICAL MECHANICS. OUR UNDERSTANDING OF THEM
 73
HAS BEEN GREATLY ENHANCED BY THE BRILLIANT INSIGHTS PROVIDED
 74
BY GALILEO, NEWTON, AND THEIR SUCCESSORS.  THE STORY OF THE WORK
 75
OF THESE EARLY SCIENTISTS IS FASCINATING READING.
 76
THESE IDEAS PROVIDE A STARTING POINT FOR FURTHER STUDY IN
 77
MECHANICS.  VERY SOON, FOR EXAMPLE, YOU WILL STUDY FALLING
 78
BODIES. WHEN A BODY FALLS THE FORCE CAUSING IT TO ACCELERATE
 79
IS ITS WEIGHT...
 80

IT HAS BEEN VERY NICE WORKING WITH YOU IN THESE PAST FOUR
 81
EXPERIMENTS. PERHAPS WE'LL MEET AGAIN IF SOMEONE WILL WRITE
 82
MORE PROGRAMS...?
 83

BEFORE WE PART, YOU'LL HAVE TO TYPE IN THE EQUATION REPRE-
 84
SENTING NEWTON'S 2ND LAW WHICH WE DEVELOPED IN THIS PROGRAM.
 85
THIS PROGRAM IS THE 4TH IN A SERIES. SINCE THE CONCEPTS DEVELOPED
 86
ARE SEQUENTIAL YOU SHOULD BEGIN BY VIEWING THE FILM LOOP
 87
'FORCE & MOTION I' AND THEN RUN 'FORCEA'.
 88

YOU SHOULD KNOW THE CORRECT ANSWER TO THIS QUESTION IF YOU'VE
 89
BEEN THROUGH 'FORCEC'. I'LL GIVE YOU ONE MORE CHANCE TO TYPE
 90
IT PROPERLY.
```

```
 91

WRONG. THE FORCE (IN N) = MASS (KG) X ACCEL (M/SEC/SEC).
 92
MULTIPLY THE MASS TIMES THE ACCELERATION TO FIND THE FORCE IN
 93
NEWTONS. TRY THE PROBLEM AGAIN.
 94

NO. 600KG X 2M/SEC/SEC = 1200N. IF YOU DON'T UNDERSTAND
 95
DISCUSS THIS WITH YOUR TEACHER AS SOON AS POSSIBLE. NOW HERE'S
 96
ANOTHER PROBLEM.
 97

NO. THE ACCELERATION IS 30/15 = 2M/SEC/SEC. F=2000 X 2 = 4000N.
 98
IF YOU DON'T UNDERSTAND DISCUSS THIS WITH YOUR TEACHER AS
 99
SOON AS POSSIBLE. READ THE PROBLEM AGAIN AND ANSWER IT
 100
CORRECTLY.
 101

INCORRECT. THE STOVE IS TRAVELLING AT A CONSTANT SPEED; THERE
 102
IS NO ACCELERATION. THEREFORE THE SUM OF ALL FORCES ON THE
 103
STOVE MUST =0. IF 250N IS BEING APPLIED TO PUSH THE STOVE,
 104
THERE MUST BE AN EQUAL AND OPPOSITE FORCE DUE TO FRICTION.
 105
ANSWER THE PROBLEM AGAIN.
 106

SORRY, WRONG ANSWER. YOU CAN FIND MASS A AND MASS B BY
 107
USING NEWTON'S 2ND LAW FOR EACH. THE NEW MASS BEING ACCEL.
 108
RATED IS THE SUM OF MASS A AND B. USE THE 2ND LAW TO FIND
 109
THE NEW ACCELERATION. ANSWER THE QUESTION AGAIN.
 110
THE TOTAL MASS = 6+2=8KG.  THE NEW ACCEL. =F/M=12/8=1.5.
 111

IF YOU DON'T UNDERSTAND, DISCUSS THIS WITH YOUR TEACHER AS
 112
SOON AS POSSIBLE. READ THE PROBLEM AGAIN AND ANSWER IT
 113
CORRECTLY.
 114
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NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

NON-COMPUTER SIMULATION AND PROBLEM SHEETS

technical report 1

FORCE & MOTION I

In this first investigation the experimenters are studying how an object's velocity changes when a constant force is applied. Throughout all the runs of today's experiments the rubber band has been stretched 60 cm. and the force is held constant as you observed in the film loop.

In the first run there were two bricks on the cart, and the experimenters gathered the following data from a careful analysis of the ticker tape pulled by the cart.

TIME (sec)	VELOCITY (cm/sec)
.1	1.6
.2	3.2
.3	4.8
.4	6.4
.5	8.0
.6	9.6
.7	11.2
.8	12.8
.9	14.4
1.0	16.0

To see how the data would differ under the influence of a different load, the experimenters made a second run with four bricks on the cart. The following data was gathered from a careful analysis of the ticker tape made in the run.

TIME (sec)	VELOCITY (cm/sec)
.1	1.0
.2	1.9
.3	2.9
.4	3.8
.5	4.8
.6	5.8
.7	6.8
.8	7.7
.9	8.6
1.0	9.6

To study the data, construct a graph plotting both curves on the same velocity vs. time axes for ease of comparison.

Next, discuss the following questions in your experiment reports:

1. What kind of relationship exists between velocity and time under these conditions?
2. The constant force gave the cart what kind of acceleration? (Remember that the acceleration of an object at any point is the slope of its velocity vs. time graph at that point.)
3. Analyze the graph and determine the acceleration in cm/sec^2 produced by the force in both runs.
4. Was the acceleration greater or smaller when the smaller mass was accelerated?

Next, list the sources of experimental error as you envision them and state the major conclusions you can draw from the experiment.

After you have completed the write-up of the experiment, do the following problem:
If an airplane's engines produce a net force which is constant and which accelerates the plane from 0 to 100 m/sec in 20 sec., what will be the plane's velocity at the end of 40 sec.?

In the first experiment, we observed that a constant force gave our cart a constant acceleration. In this investigation the experimenters are studying how different forces affect the acceleration of an object. As you observed in the film, we can very the force we apply by using different numbers of rubber loops stretched a constant length.

In this particular experiment the loops were always stretched 60 cm, and the cart was loaded with 2 bricks throughout all the runs. A different value of force was applied in each run, and the corresponding value of acceleration was determined from a careful analysis of the ticker tape pulled by the cart in each run. Here is a table of the data collected in this experiment.

FORCE (loops)	ACCELERATION (cm/sec^2)
1	8
2	24
3	40
4	56
5	72
6	88

To study the data plot a graph of Acceleration vs. Force.

Next, discuss the following questions in your experiment report:

1. What kind of relationship exists between acceleration and force under these conditions?
2. (A) If we extend the graph, what acceleration do we predict for a force of 0 loops?
   (B) Is this extrapolation justified?
3. Note that the graph does not pass through the origin. Perhaps a frictional force keeps the cart from accelerating when we apply a small positive force. If this hypothesis is true, determine from the graph the force of friction in the system.
4. Had we used a cart with greater friction then in our experiment, would the intercept on the force axis be to the right or to the left of its present location?

If, the experimenters had plotted the resultant force acting on the cart instead of the applied force, the graph would have passed through the origin. (The resultant force is the applied force minus the force of friction; a graph of the resultant force vs. acceleration represents the relationship for a frictionless cart.) On your graph paper, sketch a dashed line to display the F vs. A relationship if the cart had been frictionless.

Write an equation to fit the dashed line. Use K to represent the slope (don"t bother to calculate it).

List the sources of experimental error as you envision them, and state the major conclusions you can draw from the experiment.

After you have completed the write-up of this experiment do the following problems:

1. A spaceship is accelerating in space at 10 m/sec^2 due to the force provided by one rocket engine. Suddenly two more identical rockets are ignited providing thrust in the same direction as the first. What acceleration does the ship now experience?

2. In 10 sec. an object accelerates from rest to a speed of 300 cm/sec when acted upon by a net force (F). At the end of the 10 sec. interval F becomes one-third its original strength. What is the speed of the object

FORCE & MOTION III

In the first experiment of this series we observed that a constant force caused a body to have a constand acceleration. In the last experiment we held the mass constant and observed that the acceleration of the cart was directly proportional to the applied force. In this investigation the experimenters are studying how a constant force accelerates different masses. As you observed in the film, we can vary the cart's mass by using different numbers of identical bricks for a load.

In this particular experiment the mass of the empty cart was adjusted to equal the mass of one brick, and a constant force of SO cm was applied to the cart throughout all runs. A different number of bricks was placed on the cart in each run, and the corresponding value of acceleration was determined from a careful analysis of the ticker tape pulled by the cart in each run. Here is a table of the data collected in this experiment.

TOTAL MASS of Load and Cart (brkcks)	ACCELERATION (cm/sec^2)	1/A
2	32.0	.031
3	21.3	.047
5	12.8	.078
7	9.1	.109
9	7.1	.141

To study the data plot a graph of Acceleration vs. Mass.

Next, discuss the kind of relationship which exists between acceleration and mass under these conditions.

Our primary task as physicists is to find an algebraic expression for the relationship between acceleration and mass. A study of the graph you've just constructed suggests that it might be a 1st power inverse relationship, that is: acceleration is directly proportional to 1/mass, or mass is directly proportional to 1/acceleration. To check out, this prediction, plot a new graph of 1/A vs. Mass for each of our trials using the data collected in the experiment.

What kind of relationship exists between the two variables which you've plotted?

Write an equation to fit this graph. Use K to represent the slope (don't bother to calculate it).

Here is a problem for you to try using your graphs and the experimental apparatus: A rock of unknown mass was placed on the unloaded cart. A run was made with it applying the same force as in the other runs. An analysis of the tape indicated an acceleration of 15.0 cm/sec^2. What was the total mass of rock and cart?

What is the mass of the rock along? (This method you're using is one means of determining the inertial mass of an object.)

List the sources of experimental error as you envision them, and state the major conclusions you can draw from the experiment.

After you have completed the write-up of this experiment do the following problems:

1. A car has a maximum acceleration of 8 m/sec^2. If the car tows another car of identical mass and design, what will be the maximum acceleration?
2. Mass A accelerates at 80 ft/sec^2 and mass b accelerates at 20 ft/sec^2 when identical forces are applied. What is the ratio: MassA/MassB?

FORCE & MOTION IV

In this final section of the series, we will discuss what we've learned about force and motion and introduce a system of units in common use. In the first experiment we observed that a constant force causes a body to undergo a constant acceleration. In the second experiment we observed that acceleration was directly proportional to the net force. In the third experiment we observed what mass and acceleration are inversely related when a constant force is applied.

We may write this last statement as:

1) M is directly proportional to 1/A or

2) A is directly proportional to 1/M

From the results of Experiment 2 we can write:

3) A is directly proportional to F

Statements (2) and (3) can be combined and written as:

A is directly proportional to F/M

An equivalent statement is:

MA is directly proportional to F

or: F is directly proportional to MA

In equation form:

$$F = KMA$$

In this equation K is a constant of proportionality and its numerical value depends upon the units used to measure force, mass, and acceleration. It would have a specific value if we continued to measure force in LOOPS and mass in BRICKS. The units we used happened to be convenient for us, but they are not in common use in the world. The equation, often referred to as Newton's 2nd Law, is perhaps the most fundamental equation in classical mechanics, and the unit of force commonly used is defined so that K in the equation equals 1. In scientific work a vary common unit of mass in use today is the kilogram (kg). The basic unit of force will cause a mass of 1 kilogram to accelerate at 1 m/sec^2. This unit of force is called the Newton (N). In other words, a force of 1 Newton will cause a mass of 1 Kilogram to accelerate 1 m/sec^2. Using these units the equation is written:

$$F = MA$$

$$1\ N = 1\ kg\ m/sec^2$$

Read the information above carefully. After you understand it, do the following problems.

1. A 600 kg spaceship is propelled by a rocket engine. Its acceleration is 2 m/sec^2. What is the net force acting on the spaceship?

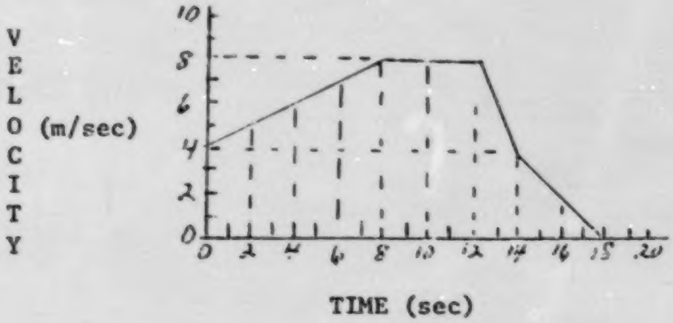
2. An 80 kg astronaut in equilibrium outside his spaceship receives a 40 Newton force from a propulsion jet attached to him. What acceleration does he experience?

3. A 2000 kg car is travelling at a speed of 30 m/sec when the brakes are applied. The car stops in 15 sec. If we assume a constant acceleration, what was the force applied by the brakes?

4. To push my stove across my kitchen floor at a constant speed of 1 m/sec. I must apply a force of 250 N. What is the frictional force acting on the [illegible]

5. A force of 12 N gives mass A an acceleration of 2 m/sec^2 and mass B an acceleration of 6 m/sec^2. What is the acceleration when the two are fastened together and the same force is applied?

The last few questions deal with the graph printed below which shows the velocity of a 10 kg object along a straight path.



6. The net force acting on the object was 0 at: (A) 0 sec; (B) 4 sec; (C) 10 sec; (D) 13 sec; (E) 16 sec; (F) None of the above.

7. The net force acting on the object was greatest at: (A) 0 sec; (B) 4 sec; (C) 10 sec; (D) 13 sec; (E) 16 sec; (F) None of the above.

8. The net force was constant between: (A) 6-9 sec; (B) 9-13 sec; (C) 13-15 sec; (D) 15-18 sec; (E) None of the above.

9. What was the acceleration of the object at 6 sec?

10. Determine the net force at 6 sec. (The object has a mass of 10 kg.)

11. Determine the net force acting on the object at 13 sec.

The ideas we've been discussing in these four "experiments" are fundamental in classical technics. Our understanding of them has been greatly enhanced by the brilliant insights provided by Galileo, Newton, and their successors. The story of the work of these early scientists is fascinating reading.

These ideas provide a starting point for further study in mechanics. Very soon, for example, you will apply them in the study of falling bodies. When an object falls the force causing it to accelerate is its own weight...

$$F = MA$$

Answers to some of the above questions are:

1. 1200 N
2. .5 m/sec^2
3. 4000 N
4. 250 N
5. 1.5 m/sec^2

11. .20 N

NEWTON'S LAW: A COMPUTER-BASED SIMULATION FOR INTRODUCTORY PHYSICS

ACQUISITION AND USE OF MATERIALS

technical report 1

Acquisition and Use of Materials

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